THE UNIVERSITY OF WARWICK

CETGI

AN ASSESSMENT TOOL FOR GLOBAL CONCURRENT ENGINEERING

EXECUTIVE SUMMARY

Submitted in Partial Fulfilment for the Degree of Doctor of Engineering

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EXECUTIVE SUMMARY ONLY AVAILABLE. THE ACCOMPANYING PORTFOLIIO CONTAINS SENSITIVE INFORMATION

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Declaration

I, Alejandro Balbontin-Posadas hereby declare that all the work presented within this submission was undertaken personally, unless otherwise acknowledged within the text, and that none of the work has been previously submitted for any other academic qualification that has not been authorised by the University.

Signed   Dated

Abstract

Industrial globalisation and the increased complexity of products promote new product development (NPD) by distributed teams. These teams facilitate the transfer of designs to manufacturing facilities, the adaptation of products to local markets and the access to engineering design talents. However, there are many industrial experiences of under performing distributed teams, such as the development of the Ford Mondeo which ran a year late and cost £ 4 billion. This Engineering Doctorate project CETGI (Concurrent Engineering and Teamwork across Global Industries) aimed to investigate and advise companies on the enabling practices of global concurrent engineering (GCE). An assessment tool for GCE was developed, embedding its enabling practices in a knowledge base and providing structured advice to manufacturing companies of electro-mechanical products.

Preliminary investigation was conducted towards the development of the CETGI tool: literature review on GCE; a benchmark study of nine current concurrent engineering assessment tools; a comparative analysis of NPD practices in the UK and the USA; a survey of NPD practices of global companies developing products in the UK; and thirteen case studies of GCE projects. The CETGI tool was then developed, consisting of an assessment process involving multifunctional teams and executives. CETGI is different to previous tools because of its knowledge base of GCE practices and its three analytical algorithms: the first, aggregates the individual answers; the second, provides a customised list of prioritised actions; and the third, generates maturity charts, providing a performance perspective and supporting benchmarking. Another novel feature of CETGI is the Internet enabled software application that supports its assessment process. The latter software is a multi-participant decision-making support system. The CETGI tool has been applied to three first tier supplier companies, two from the automotive industry and one from the transport industry aimed at fine-tuning and validating the tool. The work focused on evaluating the reliability of the questionnaire (constructed on the knowledge base) and establishing the validity and the industrial usefulness of the CETGI tool. On average, the NPD executives considered 90% of the suggested actions appropriate, selected 70% of the actions for implementation and implemented 51% of the selected actions (based on a post-assessment review at one company). The actions were estimated to reduce time-to-market and product-unit costs by the NPD executives and they rated CETGI highest in terms of promoting global product development, followed by providing an overall picture of the current product development process.

Further research opportunities have been identified such as using the CETGI tool to assess other business areas apart from GCE. This would require investigating best practices in these areas and embedding the results in specific knowledge bases. The assessment method, the structure of the knowledge base and the analytical algorithms would remain the same.

Chapter 1

INTRODUCTION

1.1 Background

New Product Development (NPD) is a strategic function undertaken by manufacturing firms, which can determine 75% of the manufacturing costs and 80% of product quality performance of a product (Dowlatshahi, 1992). Ettlie (1998) found that the investment in NPD was significantly associated with improvements of market share. The globalisation of industrial activities (Tyrone, B., 1994; Czinkota, 1998; Weiner, 1992), the increased product complexity which demands the merging of diverse core-technologies (Tidd, Bessant and Pavitt, 1997), the availability of enhanced telecommunications and information technologies (Martin, 1995) and greater ease of transportation promote the collaboration of multi-functional distributed teams working in NPD projects. The latter collaboration, so called global new product development (GNPD) facilitates the transfer of engineering know-how to manufacturing facilities, the interaction with remote suppliers, the customisation and adaptation of products to local markets, the access to engineering design talents, the divisibility of NPD programmes and the following of industrial trends (e.g. styling in Italy or California) (Miller, 1994; De Meyer and Mizushima, 1989; Gassmann and Von Zedtwitz, 1998). However, there are many industrial experiences of under performing GNPD teams. For example, fifteen development centres around the world developed the IBM's Think Pad©. In 1993, sales of this product were estimated at £ 1 billion worldwide making it the leader in the notebook sector and over one third of its sales were because of its design. However, in 1994, IBM reduced the development time of the Think Pad© from fifteen to six months by centralising its NPD activities and by using common parts (Sakakibara, 1995). In the automotive industry, in 1994 Ford developed the Contour/Mondeo with design teams in Michigan and Cologne. This project ran a year late and cost £ 4 billion. After this experience, Ford launched the programme Ford 2000 in January 1995 as part of a globalisation realignment centralising the design by using product centres (Jones, 1996).

Concurrent Engineering (CE), defined as: - "*The systematic approach for simultaneous, multifunctional and integrated design of new products, involving teamwork supported by tools, techniques and information technology applications*" (Balbontin, 1998b) was identified as an appropriate approach to support distributed NPD teams. CE is estimated to reduce development time by 30 to 70%, engineering changes by 55 to 95%, product life cycle costs by 15 to 50% and to improve overall quality by 200 to 600% (Pennell and Slusarczuk, 1989). This is in line with Terpenny and Pinchefsky (1996) who estimate a 40% reduction in time to market from using CE because less work is left for review and validation, as better product conceptualisation is achieved through up-front development.

This Engineering Doctorate (EngD) project, CETGI (Concurrent Engineering and Teamwork across Global Industries), was proposed by the consultancy firm Computer Science Corporation (CSC) and the University of Warwick's Manufacturing Group (WMG) as a response to the increasing demands of Global Concurrent Engineering (GCE), in order to assess its enabling practices and to support companies on the selection of these practices. There were initially various paths for CETGI, such as the definition of the critical factors of Information Technology (IT) to enable GCE. After reviewing the literature, various CE assessment tools were found and the development of an assessment tool for GCE was identified as a potential solution to the research problem, which can encapsulate best practices and provide advice to companies with distributed NPD. The latter was the final approach selected for the project because similar tools were studied (See Chapter 3) but none of them was focused on GCE.

1.2 Structure of the Executive Summary

This Executive summary consists of the following structure:

- Chapter 1 presents an introduction to the CETGI EngD project including its objectives and scope, describes the project phases, the portfolio structure and advises the order in which the submissions should be read.
- Chapter 2 presents the research methodology used.
- Chapter 3 reviews the literature, focusing on the key issues of the project: the best practices in GCE, the current CE assessment tools and multiparticipant decision-making support systems.
- Chapter 4 describes the key findings of the preliminary investigation.
- Chapter 5 describes the components and the development of the CETGI tool.
- Chapter 6 presents the industrial application and the validation results.
- Chapter 7 presents a discussion on the achievements of the project, the novel features of CETGI and the lessons learned.
- Chapter 8 summarises the conclusions.
- Chapter 9 proposes further work to continue this research.

1.3 Project Objectives and Deliverables

The EngD project CETGI had the following objectives:

1. To determine the critical success factors for GCE,
2. To define an appropriate assessment process for distributed teams developing products together,
3. To develop an assessment tool for GCE based on the pre-identified critical success factors and using the assessment process.
4. To test, validate and fine-tune the CETGI tool through its industrial application.

The CETGI project delivers an assessment tool, which aims to support NPD executives in identifying improvement opportunities on specific areas of global product development. Unlike previous tools, CETGI applies a structured multi-participant assessment process, strongly supported by a GCE knowledge base embedded in an Internet based software application. Using the knowledge base and the inputs from members of multifunctional teams, CETGI provides a customised list of prioritised actions to companies and a relative performance perspective. The CETGI software is a multiparticipant decision-making support system.

1.4 Scope of the Project

CETGI is aimed at manufacturing companies of electro-mechanical components[1], with distributed teams collaborating towards the development of a product within the same company. Examples of these companies are automotive, transport, white goods

[1] Chosen because of the current expertise of the Warwick Manufacturing Group

and machine tools manufacturers. The teams may belong to the same or to different business units. CETGI focuses on the organisational level, looking at the most complex type of projects (in terms of the transactions between teams and the complexity of their products) within the company assessed. Nevertheless, these projects should be representative (runners) of the company and not one-off projects (strangers). CETGI is applicable to platform, evolution (derivatives) or incremental improvement projects. Breakthrough projects with a high level of innovative content and uncertainty would require additional assessment elements (e.g. technology management), which are not currently included within CETGI.

1.5 EngD Portfolio Structure

As illustrated in Figure 1, the EngD Portfolio is made up this executive summary, the personal profile of the author and eleven submissions. Submission 1 presents the initial planning of the project; Submissions 2, 3, 4 and 8 present the initial research focused towards identifying the current practices and the critical success factors of GCE; Submission 5 benchmarks current CE assessment tools and establishes the requirements for the CETGI tool; Submission 6 describes the development of the tool; Submission 7 presents the validation and evolution of CETGI and Submission 10 presents three industrial case studies where the tool was used. There are two peripheral submissions including the guidelines for users of the CETGI tool (Submission 9) and a presentation of evidence on how industrial awareness of CETGI was promoted (Submission 11).

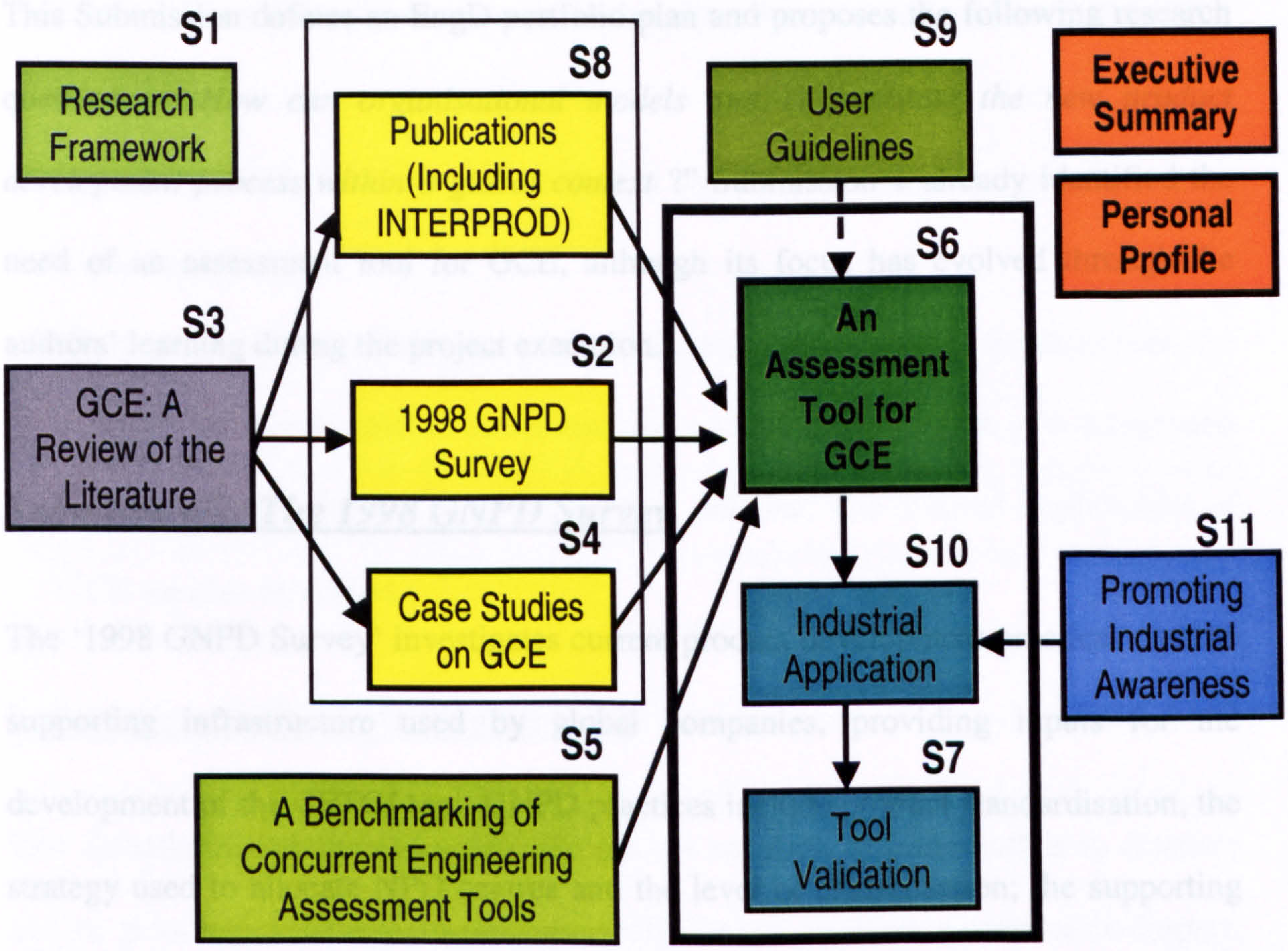

Figure 1. EngD Portfolio for the CETGI Project

Each submission is described below.

***Submission 1*: Research Framework**

The 'Research Framework' has two main objectives:

1. To propose a preliminary definition of the research objectives, the project scope and a detailed plan of activities of the CETGI project (including its resources and timing).
2. To plan the development of the authors' personal competencies required as part of the EngD.

This Submission defines an EngD portfolio plan and proposes the following research question: - "*How can organisational models and IT facilitate the new product development process within a global context ?*" Submission 1 already identified the need of an assessment tool for GCE, although its focus has evolved through the authors' learning during the project execution.

Submission 2: The 1998 GNPD Survey

The '1998 GNPD Survey' investigates current product development practices and the supporting infrastructure used by global companies, providing inputs for the development of the CETGI tool. GNPD practices include product standardisation, the strategy used to allocate NPD centres and the level of centralisation; the supporting infrastructure includes 'hard' (tools and technologies) and 'soft' practices (people related). A questionnaire was the main research instrument (responses from 46 companies). This survey had a quantitative approach and used structured statistical methods.

Submission 3: GCE: A Review of the Literature

This Submission presents and discusses literature relevant to CETGI, providing the underpinnings for the research framework and its basic components. The drivers of globalisation of new product development activities and the role of CE as an enabler of GNPD are discussed. The enabling factors of GCE are investigated, including 'soft' (people related), 'hard' and 'corporate' factors:

- 'Soft' factors include teamwork, leadership, rewards, collocation and project structures.
- 'Hard' factors include the use of design tools and techniques and information technologies.
- 'Corporate' factors include the extent of centralisation from the headquarters, the selection of organisational structures, the use of co-ordination and integration mechanisms and the use of global product policies. The cultural implications of GCE are also examined.

Submission 4: Case Studies on GCE

This Submission reports industrial case studies conducted by the author to discover and to prioritise enabling practices of GCE, based on their performance impact, establishing basic hierarchies for the development of the CETGI tool. Semi-structured face-to-face interviews were conducted with NPD executives in 30 global engineering firms based in the UK. From these companies, thirteen GCE projects were examined; projects were grouped into two categories according to their overall performance, their time to market performance and their complexity. The findings of this study were used to define some of the assessed items of the CETGI tool and to prioritise the enabling practices of GCE (read Submission 6).

Submission 5: A Benchmarking Of CE Assessment Tools

This Submission compares nine current CE assessment tools that were found by the author and defines the requirements for the CETGI tool. The objective and focus, the assessment method, the elements and the final output of each tool are examined and compared. The strengths and weaknesses of each tool are discussed, and the learning opportunities for CETGI are identified.

Submission 6: The GCE Assessment Tool

This Submission describes the CETGI assessment tool, including the assessment model and its elements (knowledge base), the assessment method and its logic, the final output to the participants and the CETGI software. This submission also discusses the novel features of the CETGI tool and the satisfaction of its requirements. Submission 6 also discusses the criteria behind the selection of specific assessment alternatives.

Submission 7: Tool Validation and Evolution

This Submission presents the work aimed at validating CETGI and it is supported by Submission 10, which presents its 'Industrial Application'. This Submission discusses the methods used for validating current CE assessment tools, defines the CETGI validation process (which is based on current tools and on new criteria defined by the author) and presents the validation results. This Submission also describes the CETGI tool evolution through the continuous learning from its industrial application and the feedback from experts. Reliability, validity and usefulness metrics were used to validate CETGI and they were compared and contrasted between all of the participating companies, and when applicable with current CE tools.

Submission 8: Publications

This Submission presents the dissemination work conducted as part of the project, discusses the feedback received and the author's learning. While completing the EngD portfolio, seven international papers have been published, including two journal papers and five conference papers:

1. Balbontin, A., Cooper, R., Sounder, W.E., and Yazdani, B., **"New Product Development Success Factors in American and British Firms"**, International Journal of Technology Management, Vol. 17, Issue 3, Pp. 259-280, 1999
2. Balbontin, A., Cooper, R., Sounder, W.E., and Yazdani, B., **"New Product Development Practices in American and British Firms"**, The International Journal of Technological Innovation, Entrepreneurship and Technology Management (Technovation), Vol. 20, Issue 5, Pp. 257-274, May 2000
3. Balbontin, A., and Yazdani, B., **"The Supporting Infrastructure for Global New Product Development"**, Proceedings of the 5th International Conference on Concurrent Enterprising, The Hague, The Netherlands, Pp. 481-488, March 1999
4. Balbontin, A., and Yazdani, B., **"Generic Firm Classification for Global New Product Development"**, Proceedings of the 6th ISPE International Conference on Concurrent Engineering: Research and Applications (CE99), Bath, UK, Pp. 20-28, September 1999
5. Balbontin, A., and Yazdani, B., **"Global New Product Development Strategies and I.T. Applications"**, Proceedings of the 19th Computers and Engineering International Conference, ASME Design Engineering Technical Conferences, Las Vegas, USA, September 1999 (Proceedings in CD-ROM, Paper DETC99 / CIE-9007)

6. Balbontin, A., and Yazdani, B., **"The Assessment Tool for Global New Product Development"**, Third International Symposium on Tools and Methods for Competitive Engineering (TMCE2000), Delft University of Technology, Delft, The Netherlands, Pp. 157-168, April 2000

7. Balbontin, A., and Yazdani, B., **"Generic Organisational Structures for Global New Product Development"**, Proceedings of the 6th International Conference on Concurrent Enterprising, Toulouse, France, Pp. 355-360, June 2000

Submission 9: User Guidelines

The 'User Guidelines' describe task by task, the way the CETGI assessment should be executed and used. These guidelines describe the selection of participants, the definition of the inputs (e.g. 'case profile'), the interpretation of the outputs (e.g. 'maturity charts' and of the 'table of actions') and the use of the software of the CETGI assessment process.

Submission 10: Industrial Application

This Submission presents three industrial case studies where the CETGI assessment process was conducted. All companies are first tier supplier companies: two from the automotive and one from the transport industry. Each case study describes task by task, the CETGI assessment process, including the outputs from each task, providing evidence used later in Submission 7.

Submission 11: Promoting Industrial Awareness

This document was submitted as evidence on how industrial awareness was promoted to obtain access to the companies in order to apply and validate the CETGI tool. Submission 11 contains an industrial report, written as a 'marketing document' that was sent to potential users of CETGI.

1.6 A Suggested Order for Reading the Submissions

The author suggests that the submissions should be read in the following order (see Figure 1):

- First of all, the 'Benchmark of Current CE Assessment Tools' (Submission 5), which explains the strengths and weaknesses of current tools and the pre-defined requirements for CETGI.
- Next, Submission 6, which describes the 'CETGI Assessment Tool'.
- Next, Submissions 4, 2, 8 (INTERPROD papers) and 3, which present the work conducted to investigate the enabling practices of GCE.
- At least one of the three Case Studies, preferably Case 3, because it applied the remote assessment capability (Submission 10), which explains how CETGI works within an industrial context.
- Finally, the validation and the reasoning behind the evolution of CETGI presented in Submission 7.

Submission 1 explains the initial aims and scope of this EngD project. The peripheral submissions explain how the CETGI tool works (Submission 9) and how industrial awareness was promoted (Submission 11).

Chapter 2

RESEARCH METHODOLOGY

2.1 Project Phases

Figure 2 illustrates the main research phases of the CETGI project.

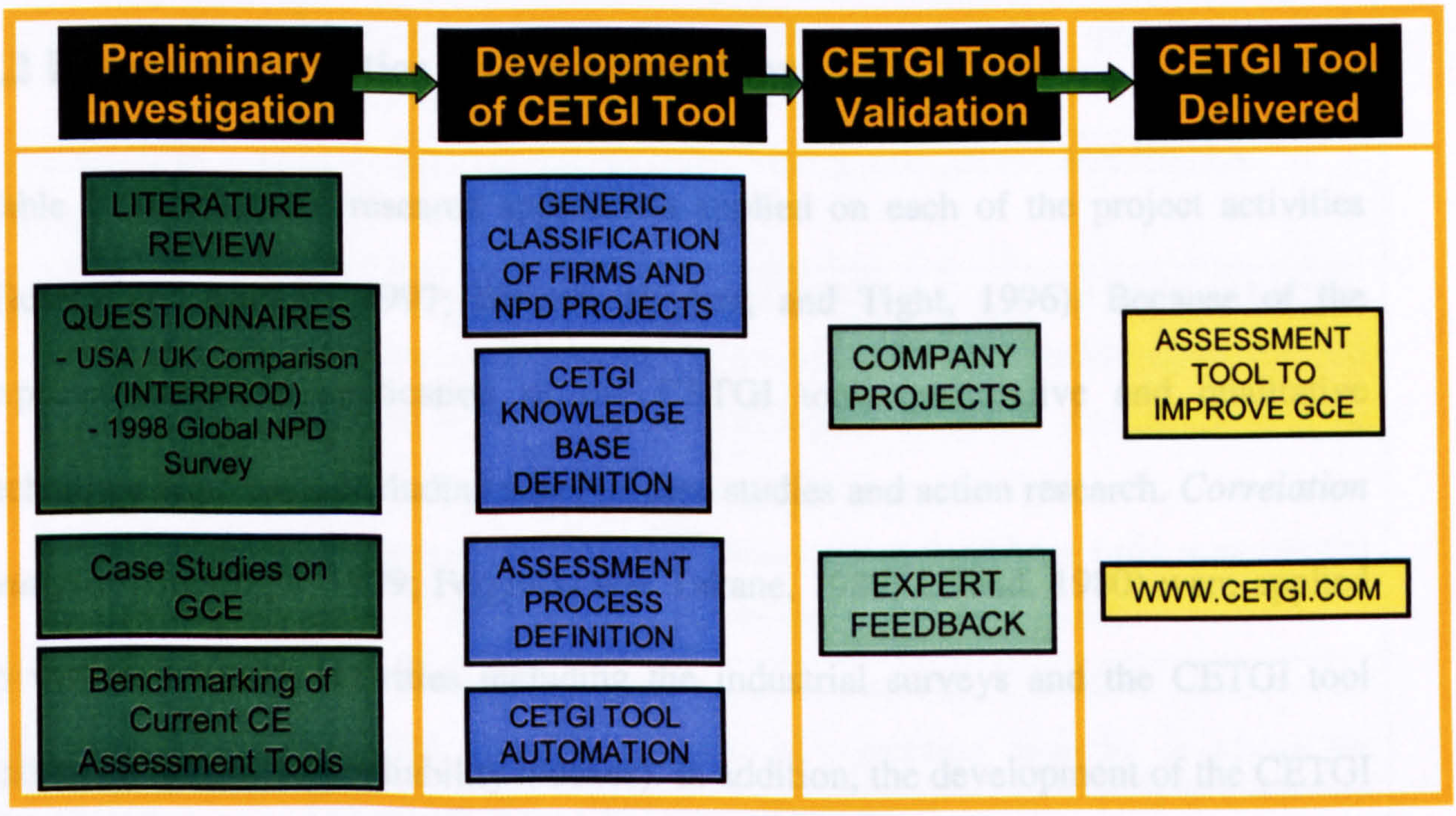

Figure 2. CETGI Project Phases

- First of all, a **preliminary investigation** of the critical success factors of GCE was conducted based on the literature review, on industrial surveys and on case studies. This research phase also included the benchmarking study of current CE assessment tools.
- Then, the **CETGI tool was developed** including the definition of its knowledge base of GCE practices and the development of its assessment method. A generic

classification of companies and products was developed and embedded in the case profile. Then, the CETGI software was developed, containing the knowledge base and analytical algorithms generating specific outputs used during the assessment process.

- The CETGI tool was then used in three companies aiming at **validating and calibrating** the tool. In addition, experts' feedback was taken into account to improve the tool.

2.2 Research Activities and Methodology

Table 1 describes the research approaches applied on each of the project activities (Hussey and Hussey, 1997; Blaxter, Hughes, and Tight, 1996). Because of the expected range of application of the CETGI tool, quantitative and qualitative techniques were used, including surveys, case studies and action research. *Correlation analyses* (Breyfogle, 1999; Ferguson and Takane, 1989; Leland, 1980) were applied to various research activities including the industrial surveys and the CETGI tool validation (calculating reliability indexes). In addition, the development of the CETGI tool required some programming, the creation of a relational database and the design of a web site[2]. *Cognitive maps* (Hussey and Hussey, 1997), the *Nominal Group Technique* (NGT) (Delbecq, Van de Ven, and Gustafson, 1975) and the cost-benefit analysis based on basic *financial decision-making* concepts (Johnson, 1970; Michaels and Wood, 1989; Price, 1993; and Lumby, 1995) were embedded in the CETGI assessment process. Finally, *action research* (Elliot, 1991; Robson, 1993; Remenyi, Williams, Money, and Swartz, 1998) was applied during the three industrial Case Studies aiming at validating CETGI.

Activity	Research Method / Skills Applied
Literature Review	Review of relevant material including books and conference papers. Electronic databases were used (e.g. BIDS, OPAC and ProQuest).
INTERPROD	Quantitative techniques including correlation analysis, t-tests, ranking, sorting and cross-tabulation.
1998 GNPD Survey	Same as above.
Case Studies on GCE	Semi-structured face-to-face interviews applying qualitative techniques (using data displays) and basic quantitative tools (including cross-tabulation, ranking and sorting).
Benchmarking of Current CE tools	Comparative analysis using ranking methods and data displays.
CETGI tool development	*Programming skills* including information systems design, relational database development and web site design. *Cognitive maps* were used as part of the 'Voice of the Company' Diagrams. An adaptation of the *Nominal Group Technique* (NGT) was used during the management consensus sessions. Basic *heuristics* and *decision rules* were created as part of the CETGI software (analytical algorithms).
CETGI tool validation and application	Industrial case studies (action research). Validation metrics were defined including the use of correlation analyses to assess the reliability of the CETGI questionnaire.

Table 1. Research Techniques and Skills Applied

Each Submission explains in greater detail the individual research methodology applied. Chapter 6 explains the validation metrics defined for the CETGI tool and the results obtained.

[2] A colleague supported the author on the programming of some PHP applications, which allowed the connectivity between the database and the Internet.

Chapter 3

PRELIMINARY INVESTIGATION: LITERATURE REVIEW

The literature on the three core themes of the CETGI project is reviewed and discussed in this Chapter: best practices in GCE (see Submission 3), current CE assessment tools (see Submission 5) and multi-participant decision making support systems (see Submission 6). The CETGI assessment tool reflects the learning from the literature.

3.1 Best Practices in Global Concurrent Engineering

3.1.1 The Critical Success Factors of NPD

Previous studies on the critical success factors of NPD can be classified into three categories (read the INTERPROD papers presented in Submission 8):

1. *The initial studies*, such as 'SAPPHO' (Rothwell, 1985) and 'NewProd' (Cooper and Kleinschmidt: 1979, 1987 and 1990), including several industry sectors. 'SAPPHO' found that successful innovators understand customer needs better and perform development work more efficiently but not necessarily more quickly. Although 'SAPPHO' included information from several countries, it did not have enough data to perform international statistical comparisons. 'NewProd' found that the proficient execution of NPD and marketing activities, marketing fit and

the development of a superior, high quality and cost effective product were critical to NPD success. 'NewProd' only considered Canadian companies.

2. *Studies focused on just one industrial sector in one particular country*, such as the 'Stanford Innovation Project' (Maidique and Zirger, 1984) and the 'Keys to New Product Success and Failure' (Link, 1987). The first project studied the electronics sector in the USA and it found that early entry into a large and growing market was critical to success. The second project focused on Australian companies and it found that the new product fit with existing marketing, technical and manufacturing skills was critical to success.
3. *International comparative studies including various industry sectors*, such as comparisons between Japan-UK (Edgett, Shipley, and Forbes, 1992), Japan-USA (Song and Parry, 1996; Song and Souder, 1997), South Korea-China-Canada (Hoon, Mishra, and Kim, 1986), and US-New Zealand (Buisson, Garrett, and Souder, 1997).

'The Contextual Framework on Factors for Success in R&D Projects and New Product Innovation' (Balachandra and Friar, 1997) reviewed literature on previous studies reporting that some of the findings of previous studies were contradictory because of the large number of factors influencing NPD success.

Although the previous studies included some engineering and teamwork elements, they were highly focused on the marketing aspects of NPD. Therefore, the author investigated the critical components of GCE from an engineering and teamwork perspective.

3.1.2 The Critical Components of GCE

Landeghem and De Wilde, (1994), Hurst (1994) and Rawcliffe (1989) have investigated the critical components of CE agreeing that these can be divided into 'hard' (tools and hardware) and 'soft' (people and organisational change) components (see Submission 3). Hurst (1994) considers that CE can be fully realised only when both components are joined. To achieve this realisation within Global New Product Development (GNPD), given rise to the following questions:

- What are the critical CE components which will enable GNPD?
- Are there additional elements that should be included with the traditional CE elements proposed by Rawcliffe (1989), Landeghem et al (1994) and Hurst (1994)? If so, what are these elements?

Aiming to respond to the above questions, Kahn and McDonough (1996) applied a case study methodology to eight companies with transnational NPD projects based in the USA from four industrial sectors: food, industrial equipment, telecommunications and electronic goods. They divided these projects in two groups: high-performing and low-performing teams. They sorted the projects in descending order by measuring the perceived success using the average of a ten point Likert scale. Kahn and McDonough found that high performing global teams use 'hard' technologies more frequently and make better use of 'soft' technologies, and that 'soft' technologies were more important than 'hard' technologies. Promoting trust was the main issue in low-performing GNPD teams whereas encouraging collective goals was important to high-performing teams. Communication and motivation to work together was given a high priority by both types of GNPD teams. The two main weaknesses of this research were the small sample size and the lack of differentiation between the specific contributions of each separate team to the project. They recognised such weaknesses and suggested further research to investigate the moderating effects of the type of work undertaken, the cycle time and GNPD processes.

Hauptman and Hirji (1999) analysed fifty cross-national CE project teams in fourteen firms in Australia, Canada, Denmark, Finland, UK and USA (including automotive, aerospace, telecommunication, shipbuilding and information technology companies), based on data collected as part of the Intelligent Manufacturing Systems (IMS) Test Case 3 of GCE, an international collaboration between academics and industry. By using Pearson correlations, Hauptman and Hirji found that integration and co-ordination mechanisms increase the effectiveness of the cross-functional team process in terms of its behaviours and attitudes, and that physical distance, time zone differences and culture have a negative effect on the team's effectiveness. In addition, they found the use of IT tools positively correlated with geographical distance and the project leader's power in non-collocated teams positively correlated with group rewards and with the use of IT tools. The IMS Test Case 3 included both collocated and distributed teams but it did not differentiate between the specific contributions of each separate team to the project. Hauptman and Hirji proposed further research to address the project type and task difficulty, specifically in terms of complexity and scale, and CE process effectiveness.

Boutellier, Gassmann, Macho and Roux, (1998) conducted an empirical study, analysing the role of IT in dispersed NPD teams based on large-scale commercial software development projects at IBM (without providing the number of projects). Their study made empirical observations such as the importance of face-to-face interaction for managing distributed projects and specific advice on how to interface IT.

Based on the previous studies, the author compared thirteen GNPD projects considering the individual team contribution to the projects and the product complexity (See Submission 4) and embedded the findings in the CETGI knowledge base. The author also investigated the type of organisational structures and formal processes applied by GNPD teams (Submissions 2, 3 and 4).

Teamwork

Because of the critical role of teams and IT in GNPD, the author studied these two areas. Within teamwork, Katzenbach and Smith (1992) studied forty-seven teams finding that high-performing teams are committed to a common purpose, they have clear performance goals, they have complementary skills and they are mutually accountable. Stickely (1994) found that the lack of structure in teams affects morale and motivation. This is in line with Cleland (1994) who highlighted the need to define formally the authority, responsibility and accountability of team members at various levels. The author also investigated the *team cycle*, which has four phases: 'forming', 'storming', 'norming' and 'performing' (Tuckman, 1965); finding that in order to speed NPD, the time spent in 'storming' and 'norming' must be reduced, as these are non-value adding phases and that 'forming' is critical because trust is developed in this phase. With regard to the team size, GNPD projects are likely to have complex products requiring the interaction of large number of individuals (50 or more) and the use of sub-teams (Katzenbach and Smith, 1993). Henke, Krachenberg, and Lyons, (1993) suggest the co-ordination of these sub-teams by a total systems group called a 'Product Management Team'. *Leadership*, *empowerment* and *rewards* are critical in GCE teams. Kahn and McDonough (1996) found that encouraging collective goals was the most important 'soft' factor for high performing GNPD teams. With regard to *collocation*, the author found opposing views. For example, Rafii (1995) presented a study conducted by Allen in 1977, which found that an increase of 10 metres between parties caused a 70% reduction in the probability of informal contact among NPD personnel; whereas Kahn and McDonough (1997) performed a survey of 514 electronics companies without finding a positive relationship between collocation and performance. In addition, De Meyer (1989) found that confidence between non-collocated teams decays over time, identifying the need for personal meetings from time to time, to act as 'confidence injections'. The latter findings were considered by the author in the knowledge base, promoting the periodic face-to-face interaction of GNPD teams and the use of IT communication tools (e.g. e-mail and video-conferencing).

Some other critical 'soft' issues of GCE were investigated including the decision-making autonomy given to these teams by their parent company or headquarters, and the impact of cultural diversity in GNPD teams. With regard to the *decision-making autonomy* given to GNPD teams by their parent company or headquarters, Chiesa (1994) investigated the use of management control systems over foreign R&D units, based on twelve multinational firms in North America, Japan and Europe, operating in technology intensive industries. Chiesa found six types of management style from 'pure centralisation' to 'total autonomy' based on the centralisation of four management functions: performance measurement, resource allocation, project selection and human resource management. Chiesa found that multiple styles are often used within a company. Therefore, CETGI also addressed the implications and the required enablers based on this level of autonomy. Although the Chiesa study focuses on R&D, some of his findings still apply to NPD: Florida (1997) studied 207 foreign R&D units in the USA finding that close to 60% of the R&D expenditure was in NPD.

The author found many studies assessing the effect of *cultural diversity* in the business as a whole (e.g. Trompenaars and Hampden-Turner, 1997; Hofstede, 1994), whereas only a few investigating the impact of culture in NPD. For example:

- Nakata and Sivakumar (1996) found that culture has an effect on the way teams initiate and implement projects. For example, cultures with a high level of 'individualism' promote NPD during its initiation phase, whereas those with a low level promote NPD during its implementation phase. 'Individualism' is defined as the relationship between the individual and the collectivity (Hofstede, 1994).
- Venkatachalam and Shore (1994) investigated the cultural impact on the use of IT to support NPD, finding that in a highly competitive environment with structured tasks, culture has little influence on the use of IT.

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Data Management tools (e.g. Engineering Data Management (EDM), Engineering Workflow Management (EWM), Product Data Management (PDM), Product Information Management (PIM)), Computer Support Collaborative Working (CSCW) (e.g. e-mail, video-conferencing and Internet) and Administration Tools (e.g. Project planning and scheduling software) were studied. Submission 3 discusses in further detail the impact of these tools in GCE.

3.2 Concurrent Engineering Assessment Tools

Assessments have been used extensively in various industrial areas such as quality (e.g.. The Malcolm Baldrige National Quality Award of the USA (US Department of Commerce, 1992) and the EFQM (European Foundation for Quality Management, 1995) self-assessment) and human resource management (Moses, 1976). Assessments have been widely used in the area of concurrent engineering and product development. Carter and Baker (1992) at Mentor Graphics and Karandikar, Fotta, Lawson, and Wood, (1992) at West Virginia University conducted pioneering work in this area. Both used specific maturity criteria within various product development elements and proposed a method for assessing such criteria. Nine current CE assessment tools were found and compared by the author in order to develop the CETGI tool. This comparison included their assessment elements, their assessment method and the final output given to the participant companies. The findings will be described in Chapter 4.

3.3 Multiparticipant Decision Support Systems

A Decision-Support System (DSS) is a system under the control of one or more decision makers that assists in the activity of decision-making by providing an organised set of tools intended to impart structure to the decision and to improve the ultimate effectiveness of the decision outcome (Marakas, 1999). A multiparticipant DSS supports the decision-making of a collective entity. Because of the multifunctional nature of CE, after studying the current CE assessment tools, the author considered it to be of industrial value to develop an assessment process introducing some features of multiparticipant DSS. This required the development of core analytical processes embedded in the CETGI software, which are based in heuristics: the criteria, methods, or principles for deciding which among several alternative courses of action promises to be the most effective in order to achieve some goal (Pearl, 1984). These processes will be described in Chapter 5.

Chapter 4

FURTHER FINDINGS OF THE PRELIMINARY INVESTIGATION

This section presents the key findings of the research phases conducted within the preliminary investigation of the project.

4.1 Identifying Best Practices in Global Concurrent Engineering

Apart from the literature review, the author carried-out the INTERPROD study, the '1998 GNPD Survey' and the 'Case Studies on GCE' in order to identify best practices, which where later embedded in the CETGI knowledge base. As illustrated in Appendix 6, the final knowledge base was created including a variety of sources and evolved through the industrial application of the CETGI assessment tool.

4.1.1 INTERPROD study

'INTERPROD' was a 19-country cross-cultural study of the life cycle factors influencing the success and failure of over 2000 new product innovations. This project was led by the 'Centre for Management of Science and Technology' (CMOST) at the University of Alabama (USA). The author obtained the questionnaire data from 49 British companies (58 successful and 41 unsuccessful projects) and the 38 American companies (59 successful and 50 unsuccessful projects) (See Submission 8). Some research variables relevant to the CETGI project were selected.

These included organisational, marketing, product, design and technology company factors (Figure 3). Correlation analysis was applied to investigate which of the previous variables were associated with the project success, defined from a commercial and a time-to-market perspective compared with competitors. Three correlation categories were defined: high (H) when the confidence level was at least 99.9%, medium (M) when it was between 99.9% and 99% and low (L) when it was between 99% and 95%. The UK and US data was analysed independently, in order to isolate the impacting factors in the success of NPD projects. Similar to other studies, Likert scales were used.

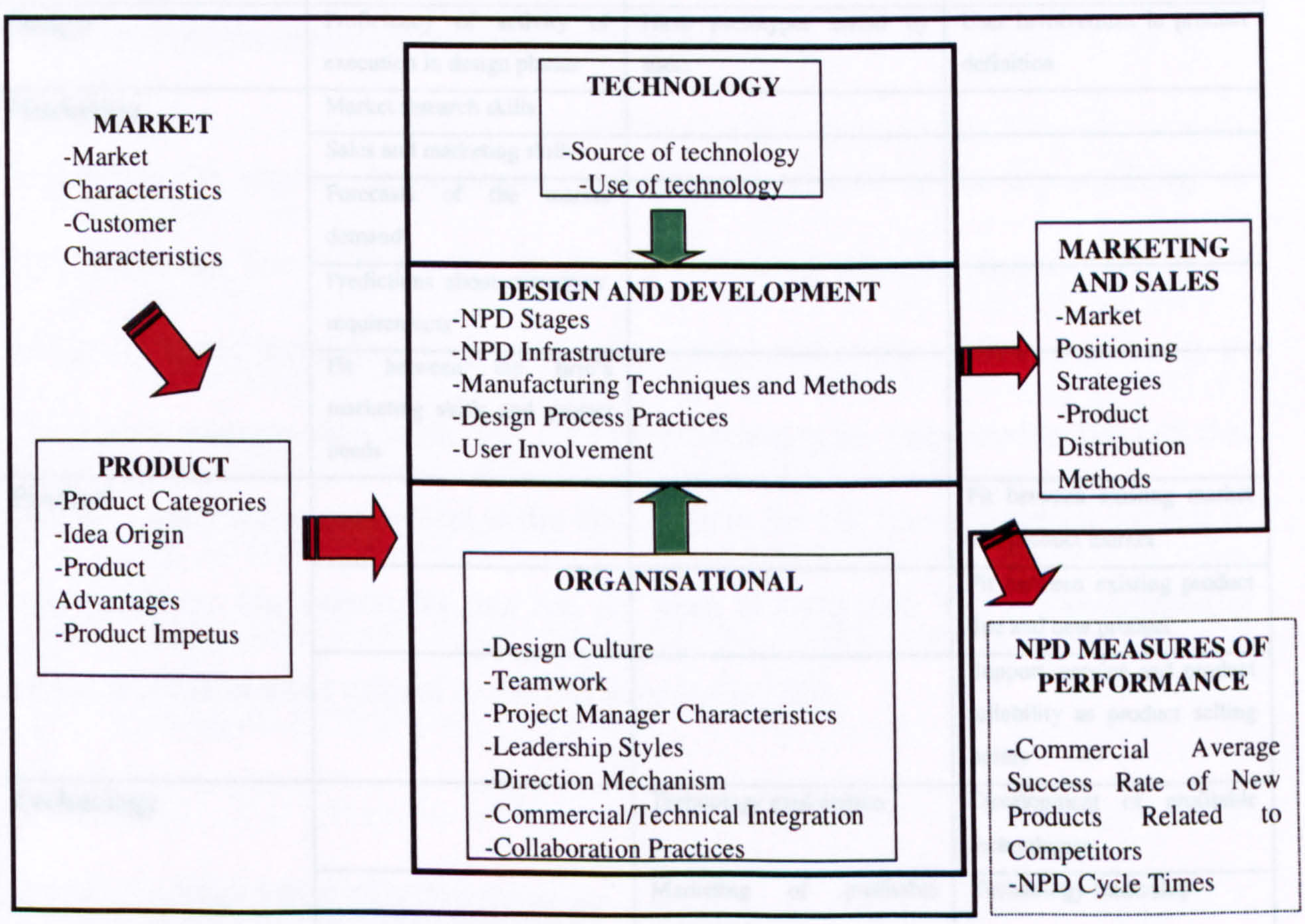


Figure 3. Analytical Framework Defined for CETGI from 'INTERPROD'

Table 2 presents the common factors associated with success in the UK and the USA (Read the paper presented in Submission 8 to review the critical factors found on each country).

	Relevance for Success		
FACTOR CATEGORY	**HIGH**	**MEDIUM**	**LOW**
Organisational	Information flow between technical and commercial entities	Contact between technical and commercial entities	Management support
	Exposure of engineering and scientific personnel to different business aspects		Project manager with the necessary technical skills
	Project manager with the necessary marketing and management skills		
Design	Proficiency of activity of execution in design phases	Have prototypes tested by users	User involvement in product definition
Marketing	Market research skills		
	Sales and marketing skills		
	Forecasts of the market demand		
	Predictions about customers' requirements		
	Fit between the firm's marketing skills and project needs		
Product			Fit between existing market and product market
			Fit between existing product line and new product
			Support, service and product reliability as product selling points
Technology		Technology exploitation	Development of profitable technologies
		Marketing of profitable technologies	Technology leadership

Table 2. Common Critical Success Factors for NPD in the UK and the USA (Source: 'INTERPROD' Study)

For example, within the organisational factors, high level of information flow between technical and commercial entities, having a project manager with the necessary marketing and management skills and exposing engineering and scientific personnel to different business aspects were found highly correlated with success. Within the design factors, proficiency of execution in the design phases (involving the reduction in design changes through the user involvement in product definition and in prototype testing) was found highly correlated with success. In addition, the NPD supporting practices were ranked according to their perceived impact and both countries had in common eight of its top ten practices: clear time goals, clear project objectives, clear priorities, improved project planning, concurrent engineering, high quality prototypes, documentation and rapid prototyping.

Shortening the product development cycle times was rated as the top challenge in both countries. The NPD process in the USA required stronger support both in the design tools and techniques (e.g. rapid prototyping) and in the skills and authority of the project manager than in the UK. The latter seems to be associated to the fact that time to market was more critical in the USA than in the UK for commercial success of new products. The reason for this has not been investigated. The empowerment of teams was found more critical in the UK than in the USA.

4.1.2 The 1998 GNPD Survey

'INTERPROD' did not focus on GCE, it had a more general focus; therefore the author conducted the '1998 GNPD Survey' (see Submission 2) investigating the current product development practices and the supporting infrastructure used by global companies. This survey was based on a questionnaire addressed to NPD executives at 637 companies with turnover greater than £ 30 million and engaged in NPD. Because of the project constraints in terms of time and budget, only companies operating in the UK were selected; however the author suggests that similar studies should be conducted in other countries to evaluate the generalisability of the survey results to GNPD. Manufacturing companies were selected from the One-Source database using standard industry codes. Response rate was of 8% (46 companies) and 64% of the respondent companies developed products in various countries. 46% of the responses came from the machinery industry and 40% from the automotive and transport industries. Similar analytical methods to those used in 'INTERPROD' were applied, using a Likert scale as the main measurement instrument. The survey addressed two main areas:

1. *The NPD strategy*, including the global product policy (e.g. Standardisation and product modularity), the level of NPD decision-making autonomy, the use of collocation and the strategies to locate NPD centres.
2. *The NPD supporting Infrastructure*, including the use of 'soft' (people related) and 'hard' (design tools and use of IT) practices, and the use of concurrent NPD process.

Key Findings in the NPD Strategy

The '1998 GNPD Survey' found that about 70% of the companies had two or more NPD centres and that 33% of the companies share several centres between their business units. The latter finding represents a potential opportunity for the application of the CETGI tool. With regard to their product policies, 44% of the companies responded that they were using standard platforms with slight variants, whereas only 18% were using universal products (Kotabe, 1998).

Key Findings in the NPD Supporting Infrastructure

'Soft' Practices

The correlation study found that the use of CE, formal NPD processes, matrix organisational structures, delegation of management of NPD centres to local managers and the NPD autonomy given to subsidiaries had a positive effect on the NPD success of global organisations (in relation to their competitors). The more complex the products the more formal the NPD process applied. 'Soft' practices were found to be more important to NPD success and speed than 'hard' practices. This was in line with the findings of Kahn and McDonough (1996). Practising teamwork to reduce time-to-market was found more critical in companies developing products worldwide than in those developing products only in their home-country (29% of the firms compared to 13% respectively). The presence of multinational team members was perceived to have a positive rather than a negative effect in meeting goals, trust and commitment; these teams were present in 73% of the respondent companies and 66% of them were collocated. Similar to the 'INTERPROD' study, top management support was significantly related to NPD success and speed. Companies who allocate rewards had higher profits per employee than those lacking them. However, half of the companies lacked rewards.

'Hard' Practices

There were no differences found in the use of design tools and techniques (e.g. Quality function deployment, creativity tools, design for manufacturing and rapid prototyping) related to the level of globalisation of NPD. The IT tools most widely applied in all companies are e-mail (used in all companies), CAD (used in 98% of the companies), project-planning software (used in 95% of the companies) and the Internet (used in 91%). Video-conferencing was used in 80% of all companies, allowing distributed teams to have frequent formal 'meetings' (20% of teams located in different countries meet daily and 80% meet weekly). Video-conferencing and project-planning software were the tools that most companies planned to implement in the next five years. The IT priorities of firms with highly distributed teams were first, communication tools, second administration tools, third engineering design tools and fourth product data management tools. Widely distributed teams used CSCW technologies more frequently than collocated teams.

4.1.3 Case Studies on GCE

Direct interaction with NPD executives involved in GNPD was undertaken in order to explore their GCE enabling practices further. Industrial case studies were conducted prioritising the GCE enablers, based on their performance impact in order to establish basic hierarchies for the development of the CETGI tool. Semi-structured face-to-face interviews were conducted with NPD executives in 30 global engineering firms based in the UK. In order to increase the generalisability of the study, companies were included with European, American and Japanese parent companies (read Submission

4). From these companies, only thirteen provided detailed information on GCE projects; their parent companies were in America (46% of the companies), in Japan (23%) and in Europe (31%). The author suggests that similar studies should be conducted to increase the sample size. As suggested by Kahn and McDonough (1996), the contribution of each participating team to the project was investigated; and as suggested by Hauptman and Hirji (1999), the project complexity was addressed. Figure 4 maps the projects in terms of their perceived complexity index and their level of interaction between the participating teams in terms of their contribution to the project (based on the spread of total engineering hours between centres). Both measures were clustered into seven categories (see Appendix 1).

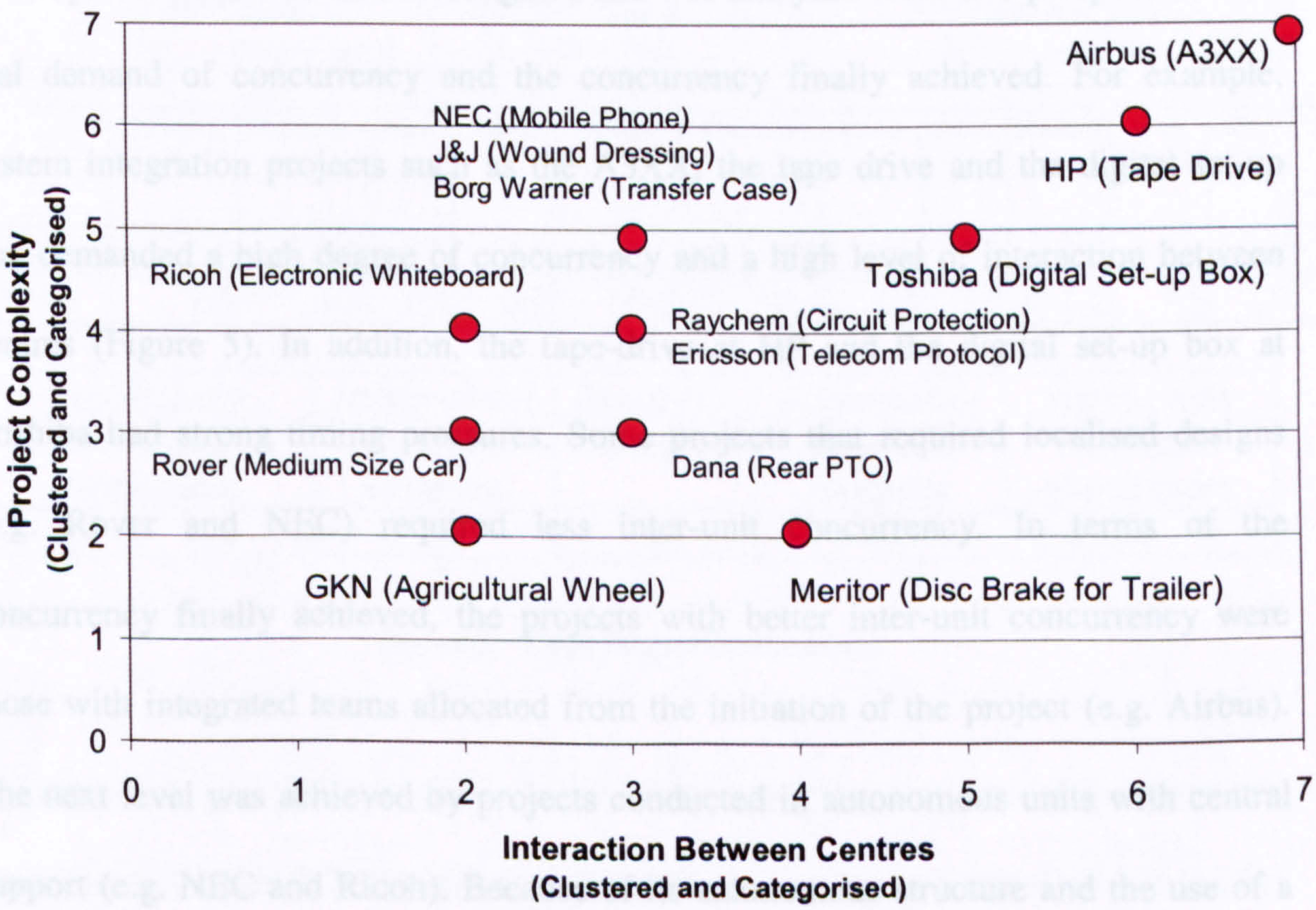
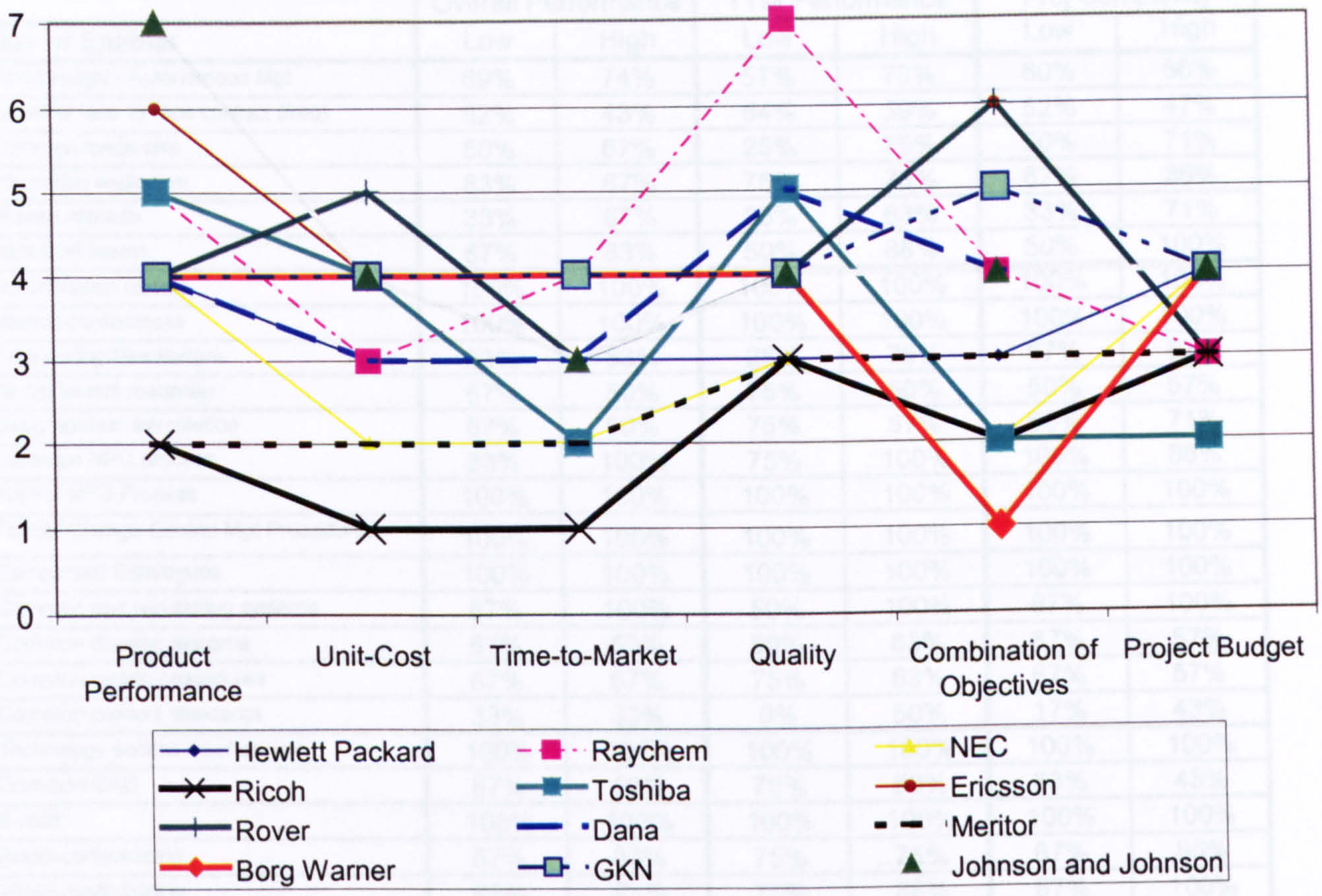


Figure 4. Projects by Complexity and Level of Interaction Between Centres

The complexity index was calculated by adding the perceived complexity of managing suppliers, the product configuration and product modules, and the product and manufacturing technologies. The A3XX was the most complex project, followed by the tape drive (from HP) and the digital set-up box (from Toshiba). As illustrated in Figure 5, six performance items were assessed on a seven-point Likert-scale[3]: product performance, unit product cost, time to market, project budget, product quality and combination of objectives. None of the projects analysed was satisfactory in all performance items. Means and standard deviations of all performance items were calculated for each project. At the end of the project, time to market was the major problem. The concurrency (extent of tasks' overlapping) between product development units was also investigated and was analysed from two perspectives: the real demand of concurrency and the concurrency finally achieved. For example, system integration projects such as the A3XX, the tape drive and the digital set-up box demanded a high degree of concurrency and a high level of interaction between centres (Figure 5). In addition, the tape-drive at HP and the digital set-up box at Toshiba had strong timing pressures. Some projects that required localised designs (e.g. Rover and NEC) required less inter-unit concurrency. In terms of the concurrency finally achieved, the projects with better inter-unit concurrency were those with integrated teams allocated from the initiation of the project (e.g. Airbus). The next level was achieved by projects conducted in autonomous units with central support (e.g. NEC and Ricoh). Because of its autonomous structure and the use of a heavyweight project manager, HP achieved better concurrency than Toshiba.

[3] Airbus was not included in this Figure because the A3XX project was not yet completed.



	Hewlett Packard	Raychem	NEC	Ricoh	Toshiba	Ericsson	Rover	Dana	Meritor	Borg Warner	GKN	Johnson and Johnson
Mean	2.7	3.2	2.5	2.0	2.2	3.7	3.6	3.1	2.3	2.4	3.4	3.4
Std.Dev	1.5	1.3	1.3	0.9	0.8	2.0	2.0	1.6	1.2	1.5	2.0	1.4

Significantly worse than expectations		Achieved our pessimistic estimates	Exactly on Target	Achieved our optimistic estimates	Significantly better than expectations	
1	2	3	4	5	6	7

Figure 5. Final Project Performance

Projects were grouped into two categories according to their overall performance, their time to market (TTM) performance and their complexity (ranked by their mean). Table 3 presents the level of use of the enablers per project (a level of use = 7 is equivalent to a 100% use) according to the previous categories.

	Overall Performance		TTM Performance		Proj Complexity	
Use of Enabler	Low	High	Low	High	Low	High
Heavyweight / Autonomous Mgt	69%	74%	57%	79%	60%	86%
Extent of face-to-face contact (freq)	52%	43%	64%	39%	52%	47%
Common leadership	50%	67%	25%	75%	50%	71%
Integration engineers	83%	67%	75%	75%	67%	86%
Shared rewards	33%	67%	25%	63%	33%	71%
High level teams	67%	83%	50%	88%	50%	100%
Co-ordination bodies	100%	100%	100%	100%	100%	100%
Internal conferences	100%	100%	100%	100%	100%	100%
Engineering Newsletters	33%	83%	25%	75%	67%	57%
Global launch roadmap	67%	50%	75%	50%	50%	57%
Geographical Job rotation	67%	60%	75%	57%	60%	71%
Common NPD process	83%	100%	75%	100%	100%	86%
Formal NPD Process	100%	100%	100%	100%	100%	100%
Formal Change Control Mgt Procedures	100%	100%	100%	100%	100%	100%
Component Catalogues	100%	100%	100%	100%	100%	100%
Common part numbering systems	67%	100%	50%	100%	67%	100%
Common drawing systems	67%	50%	50%	63%	67%	57%
Common testing procedures	67%	67%	75%	63%	67%	57%
Common product standards	33%	33%	0%	50%	17%	43%
Technology access mechanisms	100%	100%	100%	100%	100%	100%
Common CAD	67%	50%	75%	50%	83%	43%
E-mail	100%	100%	100%	100%	100%	100%
Audio-conferencing	67%	83%	75%	75%	67%	86%
Video-conferencing	83%	83%	75%	88%	67%	100%
Document control systems	33%	60%	25%	57%	20%	71%
Project management systems	67%	67%	75%	63%	50%	83%
PDM	0%	67%	0%	57%	60%	50%
Groupware (CSCW)	40%	33%	25%	43%	50%	20%

Table 3. Average Frequency of Use of Enablers in the Projects

As observed, high complexity and high performing projects more often used heavyweight or autonomous management, common leadership, high level teams, shared rewards, common part numbering systems, audio conferencing, video conferencing and document control systems. All projects used formal NPD processes, formal change control procedures and e-mail. The same was true in the case of co-ordination and integration mechanisms such as co-ordination bodies, internal conferences, component catalogues and technology access mechanisms. Face-to-face contact and common CAD systems were perceived as a highly useful, although not a common practice in the high performing teams. These findings are suggestive rather than conclusive because of the small sample size and the diverse nature of the projects studied. Spearman's rank correlation was applied (as suggested for small samples by Hussey and Hussey, 1997) without finding significant relations. However, the findings were still useful for enablers' prioritisation.

These case studies found various types of transactions between NPD units: systems integration, design customisation to local markets and contributions with critical design information. Decision making autonomy from the headquarters or parent companies was found to be critical for the on-time project completion. A selection framework for GCE enablers is proposed based on these transactions and decision-making autonomy. The previous findings were used to define some of the 'differentiating attributes' of the 'case profile' of the CETGI tool and to prioritise the enabling practices of GCE (read Submission 6).

4.2 Benchmarking Current CE Assessment Tools

The author reviewed and compared the nine CE assessment tools presented in Table 4. The table shows their year of development and authors. These tools were found after two years of continuous investigation - through literature review, participation in international CE conferences (see Submission 8) and inputs from colleagues. The selection criteria for these tools were that they had to review current CE practices and to support their improvement.

TOOL	*YEAR*	*CREATED BY*
Concurrent Engineering (CE) Assessment	1991	Carter, D. E. and Baker, B. S. at Mentor Graphics.
Readiness Assessment for Concurrent Engineering (RACE)	1992	Karandikar et al., at the Concurrent Engineering Research Centre (West Virginia University).
Product Development Process Maturity Model	1992	McGrath, Todd, Anthony and Shapiro
Simultaneous Engineering Benchmarking Tool (SEGAPAN)	1994	Landeghem and De Wilde, at the University of Ghent (Belgium).
Readiness Assessment for CE II (RACE II)	1996	De Graff, R.
Berenschot Readiness Assessment for CE (BRACE)	1997	G.P. ten Cate, at Berenschot Management Consultancy firm (The Netherlands).
Practical Approach for CE (PACE)	1997	Walker and Weber through the European collaboration sponsored by them and the European Commission under the Brite EuRam programme (BE-8037-9)
The 5X5 Framework for Product Development	1997	The Product Development Practice (UK)
Resource for CE Implementers	1999	Lettice, Smart, and Evans at Cranfield University; as part of the FAST project.

Table 4. The CE Assessment Tools Compared

Each tool was reviewed and compared according to the criteria presented in Table 5, which were determined based on the common areas described by each author.

Comparison Criterion	Description
(1.) Objective and Focus	In terms of the type of industry and products, and if the tool focuses on the organisation as a whole or on a particular project.
(2.) Method	In terms of the assessment process itself. Aspects investigated are: - The assessment phases, - The use of multiple sources to collect data, - If it is a self-assessment tool or if it requires a facilitation, - If it is automated or manual, - The number of participants and their eligibility criteria, - The level of interaction with influential individuals in the company (or decision makers) - The estimated time to conduct the assessment, - The clarity of the method and replication, - Its user friendliness.
(3.) Elements	In terms of the core areas covered, including soft, hard and strategic factors.
(4.) Final Output	In terms of the delivered results to the participants and the way to deliver these results (e.g. graphical or non-graphical). Other aspects evaluated within this criterion are the support for action prioritisation, the performance perspective (in terms of the progress metrics) and the benchmarking capability (in terms of providing a comparative reference versus other companies to the participants).

Table 5. Comparison Criteria for the NPD Assessment Tools

Key Findings

1.) The Assessment Method

Appendix 2 presents the results of comparing the assessment method of the tools (read Submission 5 for further detail on how the comparison criteria were defined). Mentor Graphics translates current company practices and requirements to specific actions using a simple process with a graphical output that facilitates the visualisation of gaps, demanding actions. Similar to SEGAPAN, PACE and the 5X5 Framework, a self-assessment method is used by Mentor Graphics' tool, requiring less time than the tools using external intervention of a facilitator (or assessor). Nevertheless, the latter tool presents a certain level of ambiguity, which hinders its objectivity and replication (see Submission 5). SEGAPAN and the 5X5 Framework reduce this ambiguity by providing a detailed element explanation to the participant. The use of multiple sources of data (e.g. interviews, consensus sessions and documentation review) reduces ambiguity, but requires external intervention. The involvement of decision-makers is a critical factor for the deployment of actions generated by the assessments, as their support is essential during the change process. Although most of the tools involve influential management, some tools use specific techniques to structure their participation, balancing the participants' contribution (Delbecq et al., 1975). RACE and its derivatives use the Nominal Group Technique (NGT) during consensus sessions, with this purpose. Because of the multifunctional nature of concurrent engineering, the majority of tools suggest the participation of various functions within the company. Here again, the larger the number of NPD knowledgeable employees involved, the higher the confidence in the output of the assessment. The use of automated processes has various advantages such as facilitating the data analysis and results generation. It also increases the flexibility to update changes, which is relevant in areas where change is constant (e.g. information technology). Its automated support allows SEGAPAN to include the highest number of elements compared to other tools while still providing the results within one day (when involving one participant). The lack of an automated process represents a major constraint for RACE and its derivatives, which require extensive calculations when aggregating the assessment results. Nevertheless, face-to-face interaction increases the ownership of actions and their potential deployment. Therefore, a combined method would be a good alternative. None of the authors provided quantitative data with regard to the replication of the assessment tools, defined by Hussey and Hussey (1997) as the extent to which a finding can be repeated. Therefore it was difficult to compare this item. The level of user friendliness of the tools varies at each of the assessment phases. For example, Mentor Graphics' assessment tool is easy to use – involving a simple questionnaire and a chart. On the other hand, RACE and its derivatives involve multiple management discussions with an average duration of three hours, De Graaf (1994) reports that participants suggested reducing this time.

2.) The Assessment Elements

Appendix 3 presents the results from comparing the assessment elements (or areas of NPD covered) of the tools. These are a critical factor of the tools since recommendations are derived from these elements, constituting the core of the assessment. The literature review was a common source for the selection of the elements. In fact, SEGAPAN is only based on literature review. Only the Cranfield tool has a preliminary industrial survey backing its development (including 80 people in 19 companies). The Mentor Graphics' tool, the McGrath maturity model, and the 5X5 Framework are mainly based on the experience of their authors. Only the RACE II tool evolved after being implemented in various companies (12 cases are reported by De Graaf, 1996). All the tools included a teamwork section, as this is a basic CE element. Only SEGAPAN and PACE covered the project organisational structure element in part. RACE II and the 5X5 Framework have a strong project management element. RACE and its derivatives place special focus on the information technology element. Various tools also cover some technology planning, supplier involvement and change management elements, which might be worth embedding within CETGI. All the tools that are based on a maturity model, describe the practices within each element across the whole maturity continuum. The 5X5 Framework and the Cranfield tool provide in detail some implementation guidelines, as this is the main focus of the tools, rather than being assessment tools. From the assessment tools, only BRACE contains some implementation guidelines based on change management.

3.) The Final Output

The final output of the CE assessment tools was compared based on five criteria: whether company specific improvements were provided, whether action prioritisation was supported, whether a performance perspective was provided, whether the tools had benchmarking capability and whether their output was graphical. Results of this comparison are presented in Appendix 4. Bobrow (1994) emphasizes that improvement initiatives must be aimed at improving the individual case, as all companies have their unique product development process. Most tools suggest company specific improvements based on the participants' judgment. Only SEGAPAN provides the option of allocating a weight to each question, however Landeghem and De Wilde (1994) report that the expert only uses these weights in the interpretative assessment. RACE and its derivatives facilitate the identification of priorities during the desired states sessions through the discussion of business drivers. None of the tools provides a customised preliminary advice for actions; this represents an innovation potential for the assessment method of new tools. With the exception of SEGAPAN and the Cranfield tool (which is an implementation framework rather than an assessment tool), all the tools provide a performance perspective through maturity phases, measuring the evolution on the implementation of practices. Nevertheless, the maturity criteria approach differs in each tool. The phases used by Mentor Graphics (task, project, program and enterprise) aim to provide guidelines in terms of the practices required according to the product complexity; McGrath and Todd use four stages (troubled, functional, integrated and world class), which are clearer than Mentor Graphics' maturity phases; RACE uses different maturity phases for the process (ad-hoc, repeatable, characterised, measured and optimising) and for the technology dimensions (initial, intermediate and advanced).

Table 6 summarises the main strengths and weaknesses of the tools. CETGI can learn from RACE II in terms of some assessment elements (e.g. product engineering and information technology), its performance perspective, its multifunctional nature and high employee involvement (also applied by the other RACE derivatives); from BRACE in terms of its method of discrimination for action prioritisation; from Mentor Graphics in terms of its simplicity, its visual output and its action prioritisation; from SEGAPAN (Simultaneous Engineering Benchmarking Tool) in terms of its automated method and quick chart generation and from the 5X5 Framework and the Cranfield tool, in terms of their implementation guidelines. The RACE II tool is most closely related to CETGI, as this tool is strong in the product engineering and information technology elements.

	Main Strengths	Main Weaknesses
Mentor Graphics	Simplicity and rapid execution. Good visualisation of potential actions. Simple priorisation guidelines.	Certain level of ambiguity and low replication. Difficulty to get an aggregate view. Elements are clustered in a confusing way.
RACE	It forces a multifunctional input through multiple sources of data, resulting in enhanced objectivity and a holistic view. Clear performance perspective through maturity levels.	Time and effort required, both by the companies and the assessors
McGrath Maturity Model	Simplicity and rapid execution. It shows in one simple matrix practices at each maturity level.	Certain subjectivity and lack of action priorisation and company specific support. Difficulty for the assessor to calculate the aggregate results.
SEGAPAN	Tool automation allows the quick chart generation even if contains over 300 assessment elements. Benchmarking capability.	Lack of performance perspective in terms of a maturity path towards improvement
RACE II	Increased objectivity because of high involvement of employees. Method enhancement through testing the tool with various companies. Elements' relevance to CETGI (e.g. product engineering, project management and information technology elements).	Complexity - making the tool time consuming and effort intensive
BRACE	It provides a new discrimination method for action priorisation and desired state selection. Best-in-class companies considered	Time and effort required
PACE	PACE provides a holistic approach supported by a knowledge platform and an implementation framework	Lack of action priorisation support. Lack of maturity levels to facilitate implementation.
5X5 Framework	It provides detailed improvement guidelines with sample goals and activities	Subjectivity which could cause a biased focus towards a specific core practice. Lack of a 'must be answered' path
Cranfield Tool	Detailed implementation guidelines and an implementation path	High extent of personal judgement in the use of the tool. Lack of a clear top level framework.

Table 6. Strengths and Weaknesses of CE Assessment Tools Compared

Nevertheless, the global focus of CETGI requires embedding various critical elements found in the literature review, the industrial surveys and case studies (Submissions 2 to 4), only covered partly by some tools: co-ordination and integration mechanisms, product development process, project organisational structure, GroupWare and product data management. None of the tools examined assesses GCE comparative capabilities, provides customised preliminary advice for actions, facilitates scenario evaluation, embeds the cost of implementing actions or has a virtual assessment capability (facilitating remote data acquisition). Therefore, these are innovation opportunities for the CETGI tool.

4.3 Defining the Requirements for the CETGI Tool

The definition of the requirements for the CETGI assessment tool was based on the previous benchmark and on the specific demands for a global assessment tool. In his Ph.D. thesis, De Graaf (1996) classified the requirements for the RACE II tool in three categories:

- *Musts*, regarded as the prerequisites that have to be covered.
- *Wants*, regarded as recommendations.
- *Bonuses*, regarded as low priority requirements or 'nice to have' features.

This categorisation was also used for the specification of the requirements of CETGI (Read Submission 5 where this specification is explained in detail). Requirements were established covering the criteria used previously to compare the tools: the assessment method, the assessed elements and the final output (Appendix 5). The requirements established as *musts* are described below (see Submission 5 where *wants* and *bonuses* are also explained).

1.) The Assessment Method Requirements

Because of its CE nature, multifunctional participation is a *must*. The decision makers' involvement is also a *must* as their action ownership is critical for change. As replication and objectivity can only be achieved through low ambiguity and standard conditions (e.g. defined participants and standard method), they are a *must*. This is in line with Byham (1976) who recommends directions for the improvement of assessment methods, stating that short definitions of the dimensions and examples of observations obtainable should be provided. Because of the constant change of some critical areas of GCE (e.g. IT infrastructure), upgradability was established as a *must*.

2.) The Assessment Elements Requirements

The relevance to GCE, the inclusion of basic CE practices and the clarity of dimensions and scales were identified as *musts*. Although most of the tools include basic CE practices, only RACE II partly covers GCE. Therefore, it is necessary to embed relevant practices found in preliminary CETGI research into the assessment tool. The clarity of dimensions and scales were also identified as *musts*, aiming to facilitate the understanding and consistency of the tool (Jeswald, 1976).

3.) The Final Output Requirements

Jeswald (1976) states that prioritisation possibilities should be provided for the organisation to determine the importance of dimensions used in the assessment model. Providing company specific improvements, supporting the action prioritisation and providing a performance perspective (metrics for guiding improvements) were identified as *musts* for the final output of CETGI.

Chapter 5

THE CETGI TOOL

5.1 The CETGI Tool Development

In developing the CETGI tool the author aimed to satisfy the requirements defined in the previous Chapter (Appendix 5), learning from the previously described tools, the industrial surveys and the literature review, and embedding in the tool the critical elements of GCE. Figure 6 presents an overview of the CETGI tool, which contains an assessment process strongly supported by an Internet based software package with the CETGI questionnaire embedded in the GCE knowledge base. Constructed on this knowledge base, CETGI suggests a 'list of customised prioritised actions' and generates 'maturity charts', providing a performance perspective by positioning the company across a maturity continuum for each of the GCE areas assessed (features defined as *musts*). NPD executives use these outputs during the assessment process, select the final actions to be implemented and define an action plan on a consensus session. The software supports the responding of the questionnaire and its analysis and it uses three analytical algorithms: the first, identifies the current GCE practices by aggregating the individual answers to the CETGI questionnaire; the second, generates a preliminary customised list of prioritised actions by conducting a gap analysis between the current GCE practices and the required enablers for the assessed case (using a 'case profile' based on the characteristics of the company and its products); and the third algorithm generates the 'maturity charts'. By modifying the 'case profile', scenario analyses can be generated with different actions. CETGI is therefore, a multiparticipant decision-support system.

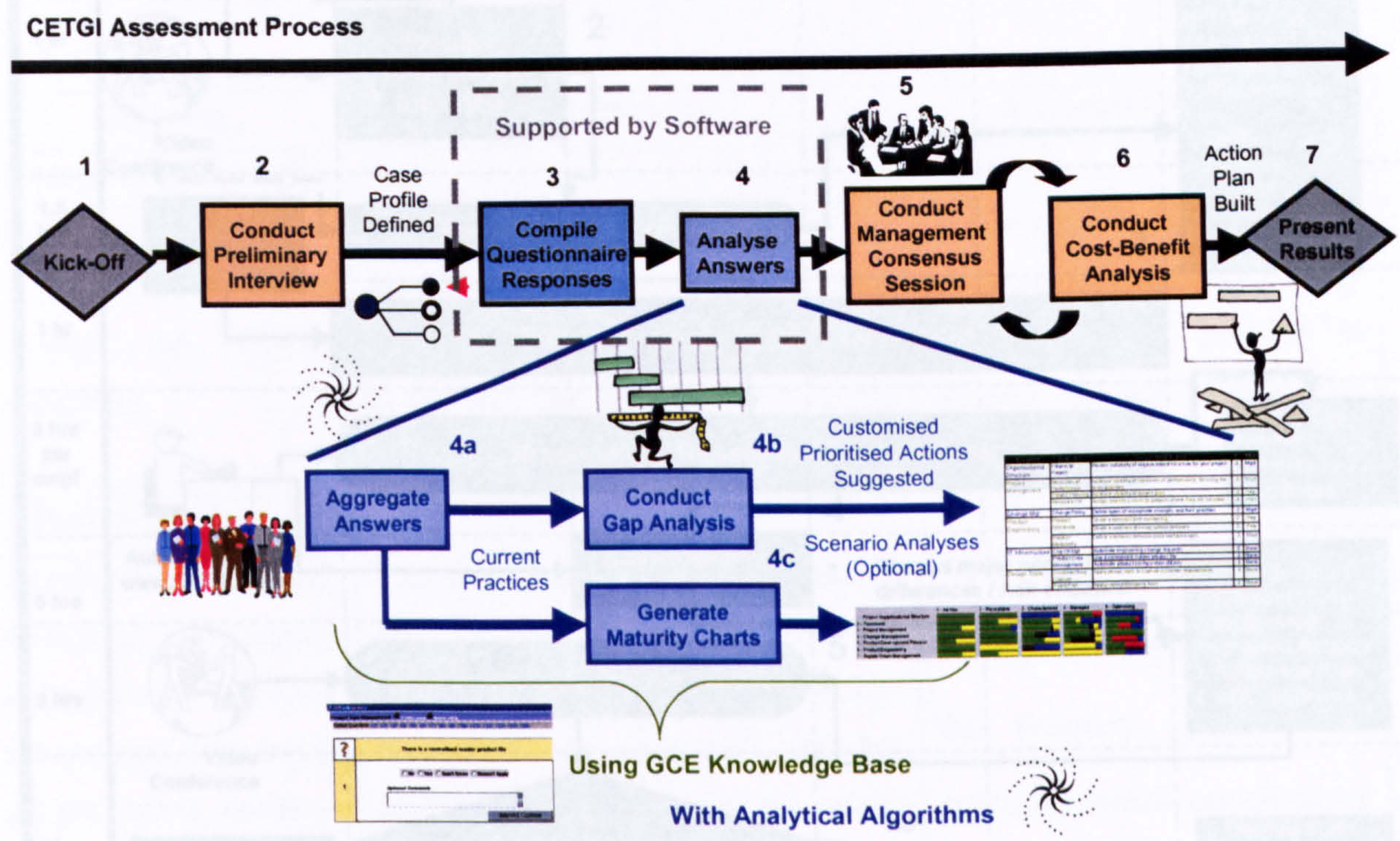


Figure 6. CETGI Tool Overview

This chapter describes the CETGI assessment process, the support software and the knowledge base.

5.1.1 The Assessment Process

Figure 7 illustrates the CETGI assessment method, showing the assessment tasks, the participants of each task, the key milestone decision points, the inputs and outputs for each task, the support technologies, guidelines and the estimated time for each task.

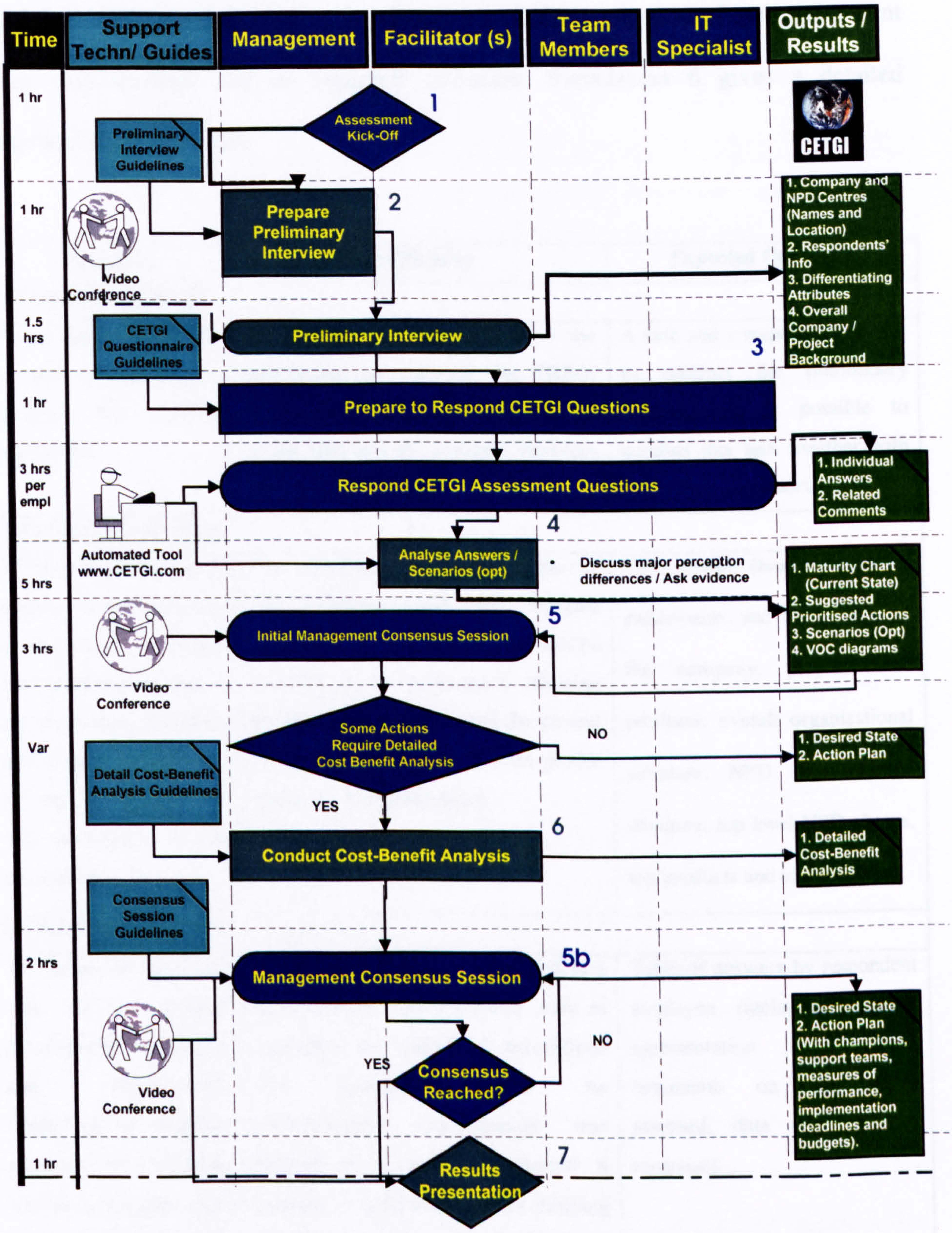


Figure 7. The CETGI Assessment Method

Table 7 describes the objective, the reasoning behind the selection of each assessment task (justification) and its expected outcomes. Submission 6 gives a detailed explanation of each task.

Objective	Justification	Expected Outcomes
1. Assessment Kick-off		
To get management buy-in and commitment to conduct the CETGI assessment.	To provide an understanding to the participants not only of the CETGI questionnaire, but also of the benefits of the tool and the required resources they have to commit.	A date and a responsible person to conduct the preliminary interview. It is possible to conduct this task together with the preliminary interview.
2. Preliminary Interview		
To understand the overall context of the company to be assessed, to profile the company case and to get the names, positions and contact information of the employees that will participate in the assessment.	This task constitutes the first contact of the facilitator with the relevant employees of the company who will be involved in the assessment, allowing the facilitator to understand the current company practices and the case profile and developing confidence.	Case profile (baseline), list of participants, and background of the company, projects and products: overall organisational structure, NPD organisational structure, top level NPD phases, top products and top customers.
3. CETGI Questionnaire		
To obtain an aggregate view of the product development practices and infrastructure applied by the company assessed, and to capture specific comments from the respondents on the assessed items.	The knowledge base is embedded in a questionnaire, which CETGI uses to aggregate the individual perceptions into quantitative data. As multifunctional participation was defined as a must, Submission 6 presents a *responding matrix* defining the functions that should be involved. The greater the number of knowledgeable participants, the more robust the assessment.	Table of answers by respondent employee (including numeric representation of answers, comments on the items assessed, date and time of response).

Table 7. Description of the CETGI Assessment Tasks

Objective	Justification	Expected Outcomes
4. Answer Analysis		
To analyse the actions advised and the maturity charts, reviewing the high priority actions and maturity gaps that should be addressed. The facilitator also generates 'Voice of the Company' diagrams. Optional Scenario Analyses can be generated, to estimate the potential additional requirements, in terms of practices and/or infrastructure, by changing the 'case profile'.	Company specific improvements, action prioritisation support and the inclusion of a performance perspective were defined as *musts* for the outputs of the CETGI tool (Submission 5). The answer analysis is a critical task to satisfy these *musts*. Scenario analyses, aim to prepare the assessed company to potential changes in NPD (Marakas, 1999).	Top priority actions, comparative maturity charts (optional) and 'Voice of the Company' diagrams. From the optional scenario analyses, a list of new or increasing requirements of practices and/or infrastructure.
5. Management Consensus Sessions		
To promote management ownership and a critical review of the CETGI actions prior to defining the action plan. Several sessions might be required to complete the action plan definition, based on the results of cost-benefit analysis, and to assign the resources for implementation.	Various authors stress the structured participation on group decision-making (Delbecq et al., 1975; Ruyter, 1996; McFadzean and Nelson, 1998; Fontana and Frey, 1994). This task applies a method adapted from the Nominal Group Technique (NGT) (Delbecq et al., 1975). Decision-makers' involvement was defined as a *must*, therefore NPD executives with investment sign-off capability must participate in this task.	From the first session, a preliminary implementation plan (including for each action: a champion, a support team, implementation deadlines and measures of performance) and a list of actions for detailed cost-benefit analysis. From the last session, a final implementation plan is expected.

Table 7. Description of the CETGI Assessment Tasks (2 of 3)

Objective	Justification	Expected Outcomes
6. Cost-Benefit Analysis (Optional)		
To estimate the financial impact (profitability) of implementing specific actions.	As stated by Lumby (1995), - "*An investment decision can be defined as one which involves the firm making a cash outlay with the aim of receiving in return future cash inflows*". Some of the enablers within the CETGI knowledge base require investment decisions to be made. Therefore, the cost-benefit analysis was included.	List of selected and rejected actions.
7. Final Results Presentation		
To communicate to senior executives and product development employees the final action plan, explaining the process towards its definition, promoting ownership and commitment from all participant employees.	This task was included as a closure of the CETGI assessment process, wrapping-up the results and actions selected for implementation.	Final implementation plan communicated.

Table 7. Description of the CETGI Assessment Tasks (3 of 3)

The above assessment process requires a *facilitator* (or assessor), defined as an individual knowledgeable about the CETGI tool, who leads the assessment (read Submission 6).

5.1.2 The CETGI Software

The software supports the previous assessment process and contains the CETGI questionnaire constructed on the GCE knowledge base. This software has evolved through the project execution from Excel© Macros to an Internet enabled system (See

Submission 7). Three analytical algorithms embedded in the CETGI software support the generation of the critical outputs used during the assessment: the first, aggregates the individual answers to the CETGI questionnaire; the second, generates the customised list of prioritised actions; and the third generates the 'maturity charts'. In addition, the software triggers and collects specific comments from each individual. The facilitator uses these comments to generate the 'voice of the company' diagrams, used during the management consensus session. This section explains the CETGI software including the knowledge base, the questionnaire design and the core analytical algorithms. Submission 6 describes in greater detail the CETGI software, including its software engineering, its operational data flow and its user interface. The software is based on a relational and structured database containing various data tables with critical assessment data.

1. The Knowledge Base

a.) The Structure and Sources of the Knowledge Base

The CETGI knowledge base, was compiled from previous research in the field (Chapter 3) and from the authors' own studies (Chapter 4). In order to structure this knowledge base, the author used a four-level hierarchy similar to RACE and its derivatives, clustering each of the GCE practices:

- *Dimensions* are the first hierarchical division, used to differentiate between 'soft' enablers (practices), 'hard' enablers (information technology and design tools) and performance;

- *Elements* are the second division, representing individual sections of the assessment including critical areas of GCE;
- *Sub-elements* are the third division, breaking down the ‘elements’ and representing the sub-sections of the assessment; and
- *Items* (or questions) contain the specific practices assessed.

Figure 8 illustrates this hierarchy.

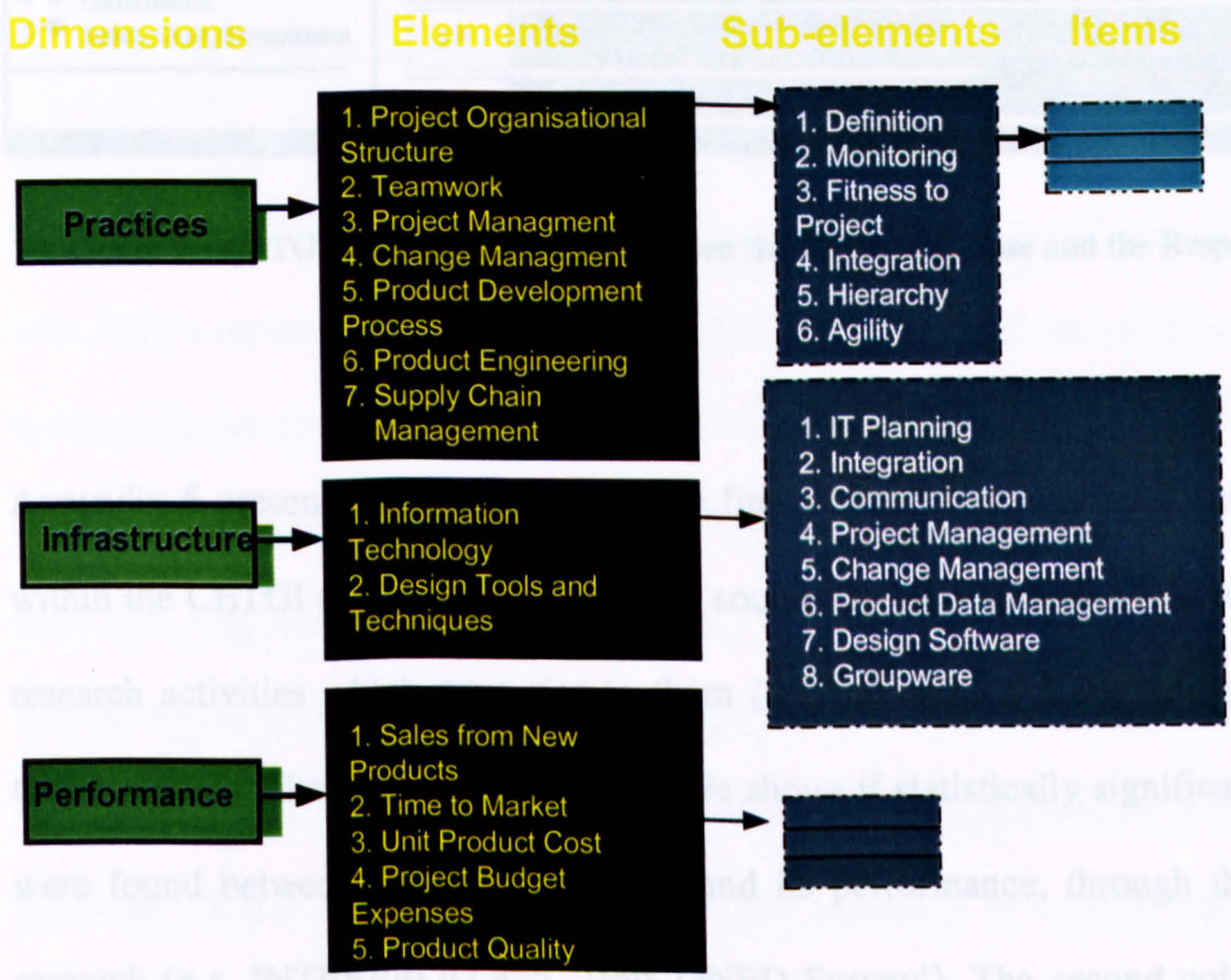


Figure 8. The CETGI Assessment Elements

Figure 9 presents a typical question as it appears in the CETGI software, where the above hierarchical framework can be visualised, providing an interface between the assessment participant (or respondent) and the GCE knowledge base.

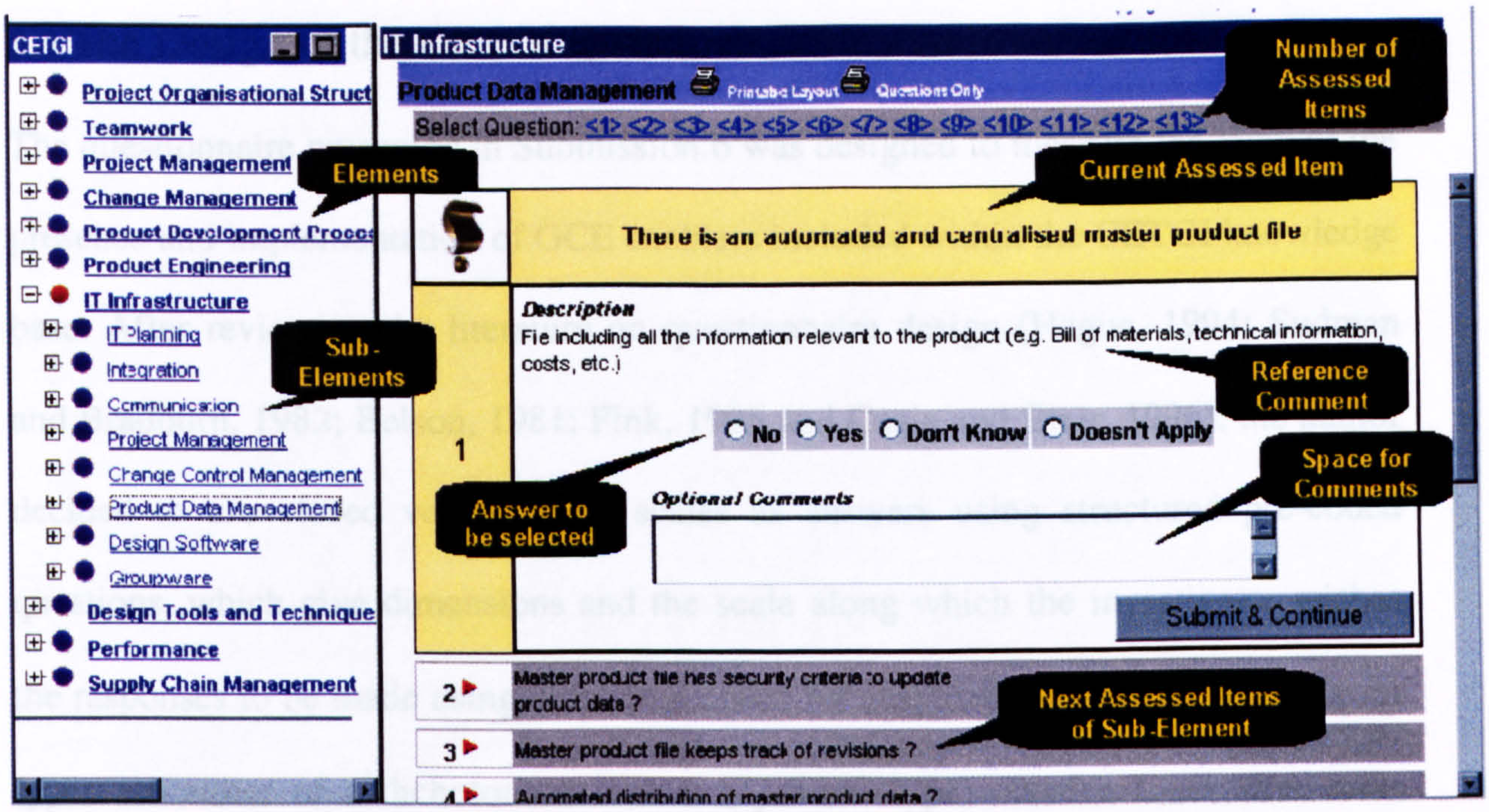


Figure 9. CETGI Software Interface between the Knowledge Base and the Respondents

Appendix 6 presents some tables with the final elements and sub-elements included within the CETGI model and it shows the source for their selection – in terms of the research activities which gave rise to them (see Submission 6 for further detail on these sources). The first column of the table shows if statistically significant relations were found between the NPD practices and its performance, through the previous research (e.g. INTERPROD and '1998 GNPD Survey'). The second column shows when a practice was found common in high performing teams either by the literature or by the 'Case Studies on GCE'. Appendix 6 also shows the literature sources for the CETGI tool elements; the other concurrent engineering assessment tools (Submission 5) that inspired the inclusion of certain elements and whether the assessment items were fine-tuned through expert feedback or industrial application.

b.) The Design of the CETGI Questionnaire

The questionnaire presented in Submission 6 was designed to measure the level of the presence and implementation of GCE enablers included within the CETGI knowledge base. After reviewing the literature on questionnaire design (Hague, 1994; Sudman and Bradburn, 1982; Belson, 1981; Fink, 1995 and Czaja and Blair, 1996), the author decided to use closed verbal rating scales as answers using structured pre-coded questions, which give dimensions and the scale along which the investigator wishes the responses to be made using numerical codes for easy data processing. The answer types are either of a dichotomous nature ('yes-no' type) or of a Likert five-scale nature (using multiple options to assess incremental levels of implementation), in line with Fink's recommendations (1995). RACE and its derivatives validated a similar approach, over several industrial applications (Submission 5). In addition to each answer type, the answers 'don't know' and 'doesn't apply' were included, in order to omit the question for further analysis. Hague (1994) pointed-out that long questionnaires which are made up entirely of closed scales can be tedious for the respondent, who may suffer frustration in not being able to express an opinion beyond the fixed choices of responses. Therefore, the capability to capture comments was embedded in the questionnaire. In order to promote the same understanding of the questions for all respondents, *reference comments* are provided in some questions (see previous Figure 9) and an *on-line glossary* was embedded in the software, defining the CETGI terminology (Figure 10) (See the detailed glossary in Submission 6). The previous attributes promote standard conditions and reduced ambiguity, identified as *musts* for the CETGI assessment method.

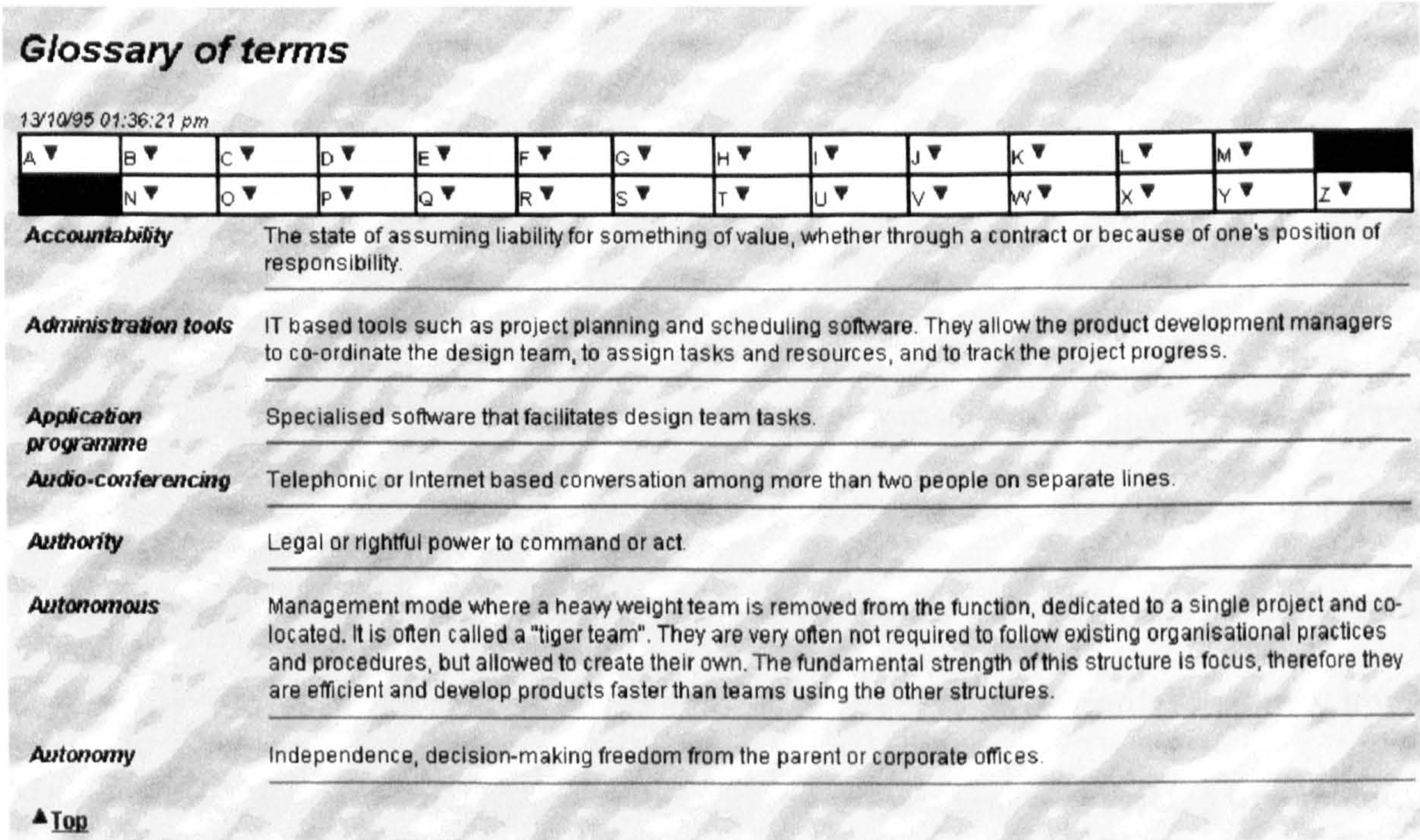


Figure 10. A Section of the CETGI Glossary

c.) The Case Profile

The 'case profile' is a critical component of the CETGI knowledge base, created in order to customise the required GCE enablers to specific companies, containing various parameters (differentiating attributes) that describe and distinguish the assessed case from others, determined through the activities conducted to define the GCE enablers. This profile should be compiled based on representative type of projects (those frequently undertaken) with the highest level of complexity in terms of the transactions between teams and the complexity of their products (their levels of bills of materials and interfaces between subsystems (See Meyer and Lehnerd, 1997)). 'Differentiating attributes', their levels, specific comments and examples are presented in Appendix 7. It was decided to use a small number of 'differentiating attributes' and three levels for each attribute, in order to simplify the case profiling

(Read Submission 6 where the criteria behind the definition of the 'case profile' is explained).

d.) The Maturity Levels

The inclusion of a 'performance perspective' was defined as a *must* for the CETGI tool output and 'clarity of dimensions and scales' was identified as a *must* for the CETGI elements (see Submission 5). Therefore, as RACE and its derivative tools have the most clear performance perspective (De Graaf, 1996), similar maturity levels were embedded in CETGI (Table 7). Each item (or question) was related to a maturity level (see Submission 6), so that an implementation path could be advised for the participant companies. Some practices within one maturity level are a requirement prior to the implementation of practices within the maturity level above (an example is given in Submission 6). Visualising their stage of maturity allows companies to understand their strengths and weaknesses, and where further effort and resources should be allocated.

Practice Dimension	
Ad Hoc	Ill defined procedures and controls. Management not applied consistently. Procedures are informal and not documented.
Repeatable	Standard targets and practices. Formal and documented procedures. False teams may exist.
Characterised	Documented procedures and standards are followed and understood. Targets are reported periodically.
Managed	NPD is well controlled. Tools to manage and control the process are used. True teams exist.
Optimising	High degree of control. Continuous improvement by using process metrics and lessons learned

Infrastructure Dimension	
Absent	Lack of information technology infrastructure or use of design tools and techniques.
Basic	Under utilisation and inefficient use of technology or design tools and techniques. Minimum use of IT. No multidisciplinary support. "Point" solutions provided.
Intermediate	Moderate use of proven technologies. Basic systems are compatible. Employees know how to use technology.
Advanced	State of the art technology is used and updated. Systems are compatible. Tools to increase team effectiveness and interaction are used. Multidisciplinary support.

Performance Dimension	
Inferior	More than 50% below targets. Much worst than competitors.
Average -	Up to 50% below targets. Worst than competitiors.
Average	Company has met its NPD targets. This figure is similar to competitors.
Average +	Up to 50% above targets. Better than competitors.
Superior	Over 50% above targets. Much better than competitors.

Table 8. The CETGI Maturity Levels

2. The Analytical Algorithms

These algorithms were developed specifically for CETGI constituting its 'inference engine' or control mechanism of the knowledge base (See Klein, 1990), deciding on which rules to execute and in which order. These algorithms are based on *heuristics* criteria (See Pearl, 1984 and Reeves, 1995), using the GCE knowledge base to support multi-participant decision-making (MDM). The critical analytical algorithms are described below.

a.) The List of Prioritised Actions

An analytical process generates a list of prioritised actions customised for each company, based on the pre-determined impact of each question item (practice or infrastructure) on the 'case profile' of the company. This list ensures the visibility of actions and supports action prioritisation, identified as a *must* for the assessment output. A database table with the questions has a pre-determined priority rank by default and a priority rank telling CETGI the estimated impact that each question item could have according to the level of differentiating attribute applicable. For example, Table 9 shows the pre-determined priorities within the sub-element *resource control* within the element *project management*.

Element: Project Management SubElement: Resource Control			
Q.No	Question	PriorityRnk Default	DiffAttrAff
1	Incurred costs are recorded and monitored periodically	2	73-3,83-3
2	Formal mechanisms in place for budget approval	2	43-3,83-3
3	Clear criteria defined for budget allocation at each management layer	1	12-2,13-2,23-2,32-2,33-2,43-2,83-2,83-3
4	Project manager knows what are the areas where more costs are incurred in the development process	2	73-3, 83-3
5	Costs are assigned and tracked for each project where they are incurred	2	43-3,73-3,83-3

Table 9. Customising Priority Ranks

There is a column representing default priorities – the example contains four items with a medium impact (2) and one item with a low impact (1). Another column represents the potential changes of impact according to specific differentiating attributes ('DiffAttrAff'). This column has data with the following format[4]:

Differentiating Attribute $_n$ | Level Affected $_m$ - Impact , Differentiating Attribute $_n$ | Level Affected $_{m+1}$ – Impact , Differentiating Attribute $_{n+1}$ | Level Affected $_m$ - Impact

Where **n**: number of differentiating attribute ($1 \leq n \leq 10$)[5]

m: level of differentiating attribute affected ($1 \leq m \leq 3$)

impact: level of potential impact of the practice or infrastructure ($1 \leq \text{impact} \leq 3$)

[1= low / 2= medium / 3 = high]

Each relation is separated by a comma and contains three digits with a line between the second and the third digit[4]. The first digit represents the differentiating attribute category affected, the second digit represents its level affected, and the third digit represents the potential impact of the action item. Submission 6 gives specific examples on the latter. The criteria applied to determine the 'PriorityRnkDefault' are described below:

- If a strong or medium statistical significance[6] to product development success was found through the INTERPROD study or if the relevance of an item was quoted as a basic critical success factor by other studies[7], a value of 3 (high impact) was assigned to this parameter. As this value is the maximum priority, the question item affected has its field 'DiffAttrAff' empty.

[4] The differentiating attributes affected are also represented by the table 'DiffAttrAff'. This table must be changed when a relation is modified, as the CETGI analytical process used this table (as it made the process quicker). The representation within the table 'questions' is used only for easier visualisation.
[5] Note that more than 10 differentiating attributes could be used.
[6] Statistical significance was strong when the confidence level was at least 99.9%, medium when the confidence level was between 99% and 99.9%, and low when it was between 99% and 95%
[7] For example, Katzenbach and Smith (1992) found that high performing teams have a common purpose, complementary skills and accountability (Submission 3).

- If a low statistical significance for product development success was found through the INTERPROD study[8], a value of 2 (medium impact) was assigned by default.
- Otherwise a value of 1 (low impact) was assigned to 'PriorityRnkDefault'.

The criteria applied to determine the 'DiffAttrAff' are as follows:

- If a common practice was found in high performing teams through the GCE Case Studies, the 'DiffAttrAff' was assigned a value of 3, based on the characteristics of the global projects (Submission 4). For example, heavyweight or autonomous management was common in high performing teams developing complex products. Note that these relations were not statistically proven (as there were only thirteen projects examined), and hence the advice given by the CETGI tool is suggestive rather than conclusive. As each case and company is different from the others, the *management consensus sessions* and *cost-benefit analysis* were included within the CETGI assessment method promoting the selection of suitable NPD actions.
- If a practice was quoted as important in the literature related to specific differentiating attributes present, or if a practice was rated as important but it was not common in high performing teams (Submission 4), a value of 2 was assigned to 'DiffAttrAff' (Submission 3).

Figure 11 illustrates the process used to determine the level of impact applicable.

[8] Note that also related practices, with different wording were prioritised through the same method. For example, 'avoiding design changes' was found to have a low significance to success. Therefore, the practice 'Formal change request form is used for authorising changes' was given a priority 2 by default.

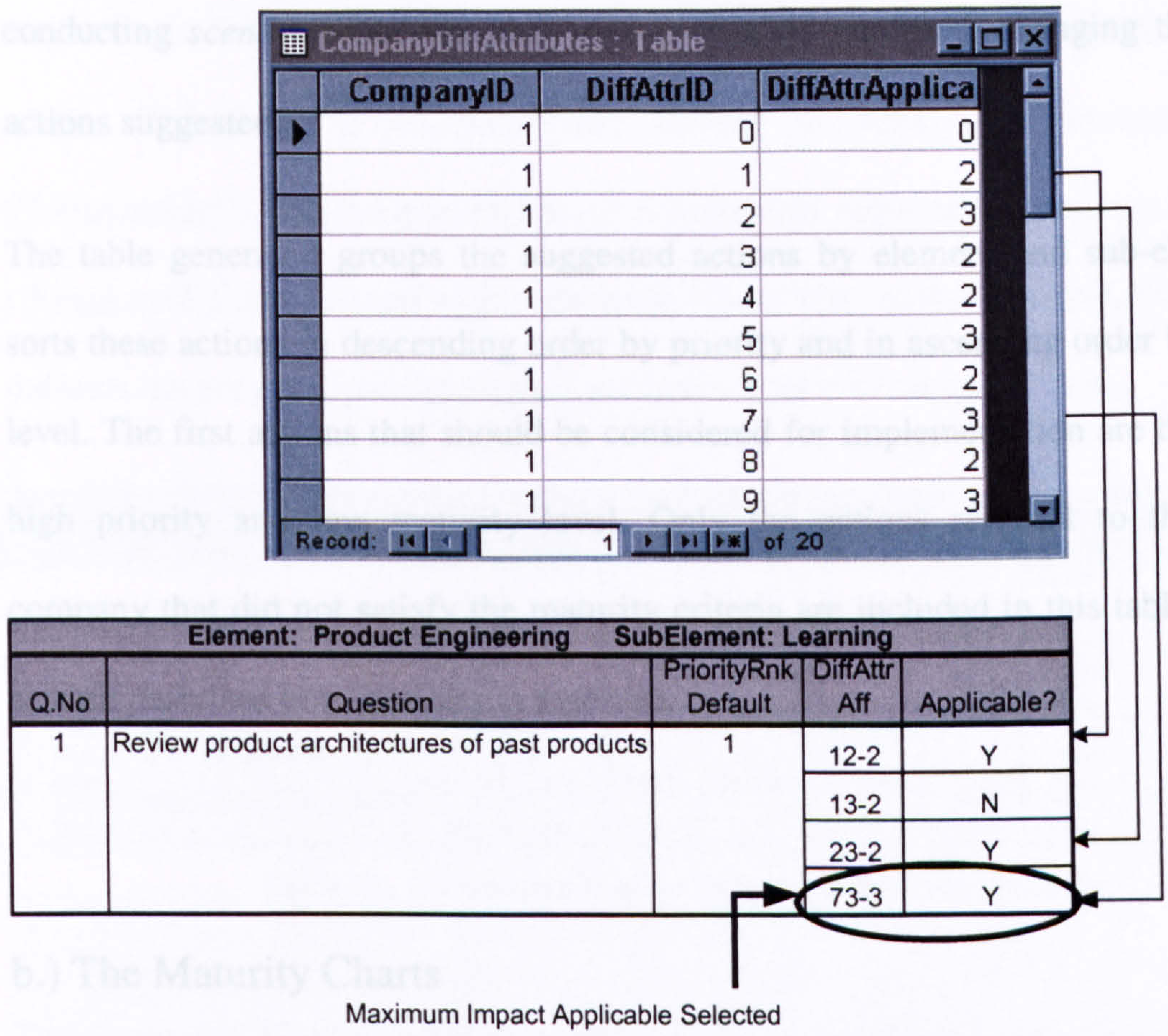


Figure 11. Selecting the Maximum Impact Applicable

As stated by Marakas (1999), - "*In most situations we do not need to know the exact probability of a particular outcome or event. Rather than a single probability estimation, we might benefit from an estimation of the worst-case scenario and the best-case scenario*". Therefore, CETGI determines the prioritised actions based on the worst-case applicable to the company assessed, by looking at its 'case profile' and by selecting the potential maximum impact that each practice or infrastructure could have. The query process 'C_CompanyActions' selects the maximum priority applicable to the company from the table 'DiffAttrAff' (See Submission 6). When conducting *scenario analyses*, the 'case profile' is modified, changing the table of actions suggested.

The table generated groups the suggested actions by element and sub-element and sorts these actions in descending order by priority and in ascending order by maturity level. The first actions that should be considered for implementation are those with a high priority and low maturity level. Only the actions relevant to the assessed company that did not satisfy the maturity criteria are included in this table. The next section describes how maturity is assessed.

b.) The Maturity Charts

Providing a performance perspective was identified as a *must* requirement for the CETGI tool. Maturity criteria are used to provide this performance perspective. To determine maturity, CETGI calculates first the cumulative percentage of answers for each answer type. When a majority selects either or both 'don't know' or 'doesn't apply' answers, the assessed items are omitted. Marakas (1999) presents the taxonomy of decision structures, differentiating a *consensus* from a *majority* decision. In a *consensus*, all decision-makers must agree. In a *majority*, only a stated percentage must agree. By quantifying the answer level of the majority (two thirds of the respondents), CETGI translates qualitative information into a quantitative form (Read Submission 6). An algorithm was created, to estimate the individual maturity, based on decision-rules described in Submission 6 (Klein, 1990; Silverman, 1987):

As shown in Table 10, the level of maturity to which each assessed item (or question) relates ('Mat.Level'); its minimum answer to satisfy its maturity criteria ('MinAnswer'), and the percentage of respondents required to satisfy such criteria ('RespLevel')[9] are defined within the table 'Questions' of the database. Submission 6 presents the previous pre-determined parameters for each assessed item.

Element: Teamwork Sub-element: Core top level team											
Q.No	Question	Answer1	Answer2	Answer3	Answer4	Answer5	Answer6	Answer7	Min Answer	RespLevel	Mat.Level
1	There is an overall core project team	No	Yes				Don't Know	Doesn't Apply	2	0.67	Managed
2	Overall core project team has multifunctional representation	Not at all	Little	Partially	Generally	Completely	Don't Know		4	0.67	Ad-hoc
3	Overall core project team has multiregional representation	Not at all	Little	Partially	Generally	Completely	Don't Know	Doesn't Apply	4	0.67	Optimising
4	Overall core project team has representatives from each bottom level team	Not at all	Little	Partially	Generally	Completely	Don't Know	Doesn't Apply	4	0.67	Optimising
5	Top core level team has a maximum of ten members	No	Yes				Don't Know	Doesn't Apply	2	0.67	Repeatable

Table 10. Parameters Used to Estimate Individual Maturity

The parameter 'MinAnswer' represents the minimum answer to satisfy the maturity of each question item. This parameter was established as follows:

- All question items with a 'yes-no' answer have a 'MinAnswer' equal to 2 (representing 'yes') – most of these items are infrastructural, assessing if a particular resource (e.g. Information technology tool) or practice (e.g. use of rewards) is present in the company,
- Question items with a Likert-scale type of answer have a 'MinAnswer' equal to 4 (representing 'most', 'generally', 'nearly always' and 'formal and sometimes used'). Therefore, two thirds of the respondents have to respond either with an answer level of 4 (previously described) or 5 (representing 'all', 'completely', 'all the time' and 'formal and always used'). After using the CETGI tool in industry, some of the items with this type of question were calibrated to an answer level of 3 (See Submission 7).

[9] It was decided to use *two thirds* of respondents as majority criteria for all the questions, however, in order to embed flexibility into the tool the majority criteria can be defined individually by changing the 'RespLevel' field within the table 'Questions' of the knowledge base.

Figure 12 illustrates an example of this maturity chart. A colour coding was used in the CETGI maturity chart, based on the traffic light system widely used in industry, increasing the visualisation of actions compared to the other CE assessment tools.

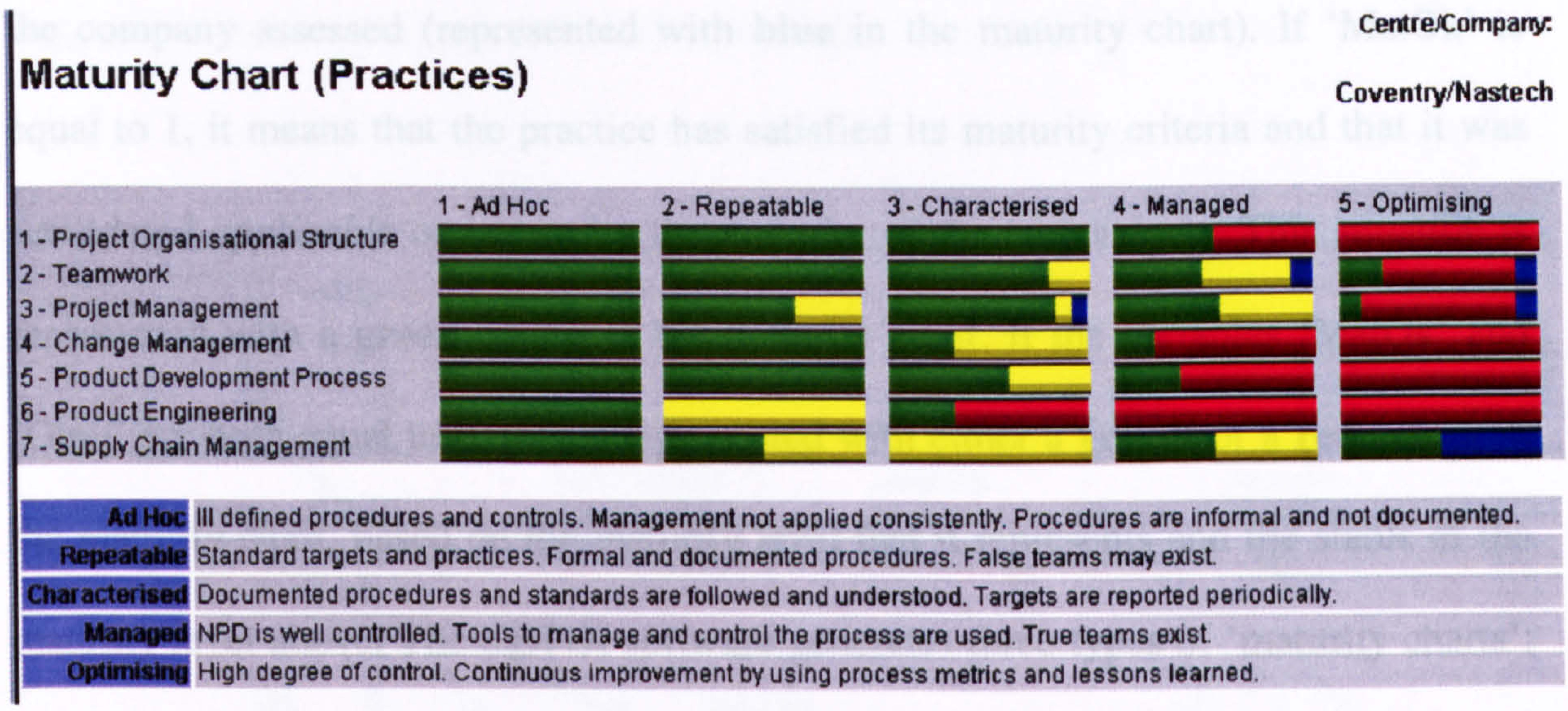


Figure 12. Practices' Maturity Chart Generated with CETGI Software - Example

This chart must be read together with the table of aggregate answers (Table 11), which last two columns show the value of two variables: 'Omit' and 'MatOK'. These two variables evaluate the current level of implementation of each assessed practice (see Submission 6).

Subelement	Question	1	2	3	4	5	6	7	Tot	GTot	Ac5	Ac4	Ac3	Ac2	Ac1	RspLv	TypeAns	MinAns	MatLev	Omit	MatOK
Element: Teamwork																					
Purpose Awareness	Team is aware of its overall project objectives			3	9	1			13	13	8%	77%	100%	100%	100%	67%	3	4	Ad Hoc	0	1
Top Management Involvement	Senior management actively participates in this project			2	7	3	1		12	13	25%	83%	100%	100%	100%	67%	4	4	Managed	0	1
Core top level team	Overall core project team has multifunctional representation			2	8	2	1		12	13	17%	83%	100%	100%	100%	67%	3	4	Ad Hoc	0	1
	Top core level team has a maximum of ten members	2	2				8	1	4	13	0%	0%	0%	50%	100%	67%	1	2	Repeatable	1	0
	There is an overall core project team	1	11					1	12	13	0%	0%	0%	92%	100%	67%	2	2	Managed	0	1
	Overall core project team has multiregional representation		3	1	2			7	6	13	0%	33%	50%	100%	100%	67%	2	4	Optimising	0	0
	Overall core project team has representatives from each bottom level team	1	1	2	7			2	11	13	0%	64%	82%	91%	100%	67%	3	4	Optimising	2	0

Table 11. Table of Aggregate Answers

The variable 'Omit' can have three values: 0 means that more than half of the respondents consider that the assessed company must implement this practice, 1 means that they did not have an answer for that question (represented with **black** in the maturity chart) and 2 means that they considered this practice non-applicable for the company assessed (represented with **blue** in the maturity chart). If 'MatOk' is equal to 1, it means that the practice has satisfied its maturity criteria and that it was considered *applicable* or *known* by the majority of the respondents. This situation is represented with a **green** colour in the maturity chart. If the variables 'MatOk' and 'Omit' are both equal to 0, this is represented with either a **yellow** or a **red** colour in the maturity chart, based on the maturity level that it represents and the status of the maturity level above. The CETGI software generates three types of 'maturity charts': the first includes the overall NPD practices; the second, the use of information technology supporting NPD; and the third includes the use of design tools and techniques (see Submissions 6 and 10).

Voice of the Company Diagrams

CETGI can trigger and capture specific comments from each respondent for further review, during the management consensus session. These comments known as 'Voice of the Company' (VOC), allow the participants in the assessment to express their views for further review. A *cognitive map* is generated with the VOC (Figure 13) used as a – "*method of analysis to structure, analyse and make sense of written or verbal accounts of problems*" (Hussey and Hussey, 1997). The CETGI software captures optional comments by each assessed item. However, the *facilitator* must review the VOC for each element, placing special attention on repeated comments and clustering related comments into subcategories, ensuring that a generic concept is super-ordinate to specific items that contribute to it, building-up a hierarchy (Ackermann and Cropper, 1990). VOC diagrams frequently provide symptoms and specific suggestions in terms of actions to be implemented.

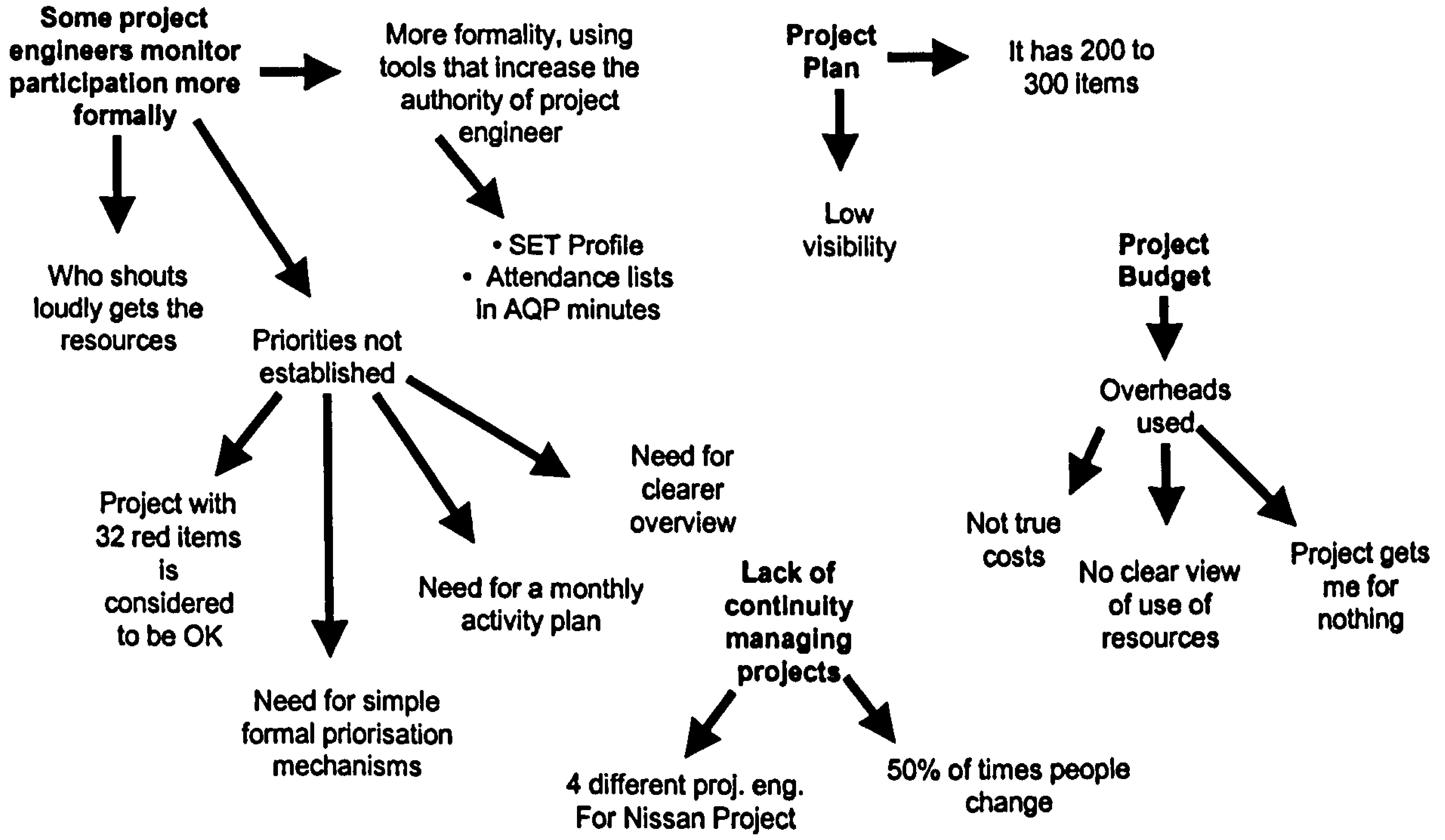


Figure 13. Voice of the Company Diagram – An Example

5.2 CETGI Tool Evolution

The CETGI tool evolved from its initial version through the project execution based on lessons learned from three industrial Case Studies (presented task by task in

Submission 10) and from the feedback from experts. CETGI evolved in three main areas (read Submission 7):

- The overall assessment system (from paper-based to web-enabled). Because of its global nature, the author decided to use Internet technologies, providing CETGI with a remote data acquisition capability, being able to get inputs from distributed teams.
- The knowledge base modification (adding, eliminating and rephrasing the assessed items; adding new reference comments; and defining new terms within the glossary) and,
- The calibration or fine-tuning of 'minimum answers', decision rules embedded in the knowledge base and required to consider a practice in place (see Submission 6).

Two evolution iterations were made: during Case Study 1 and after completing Case Studies 2 and 3. CETGI was modified based on the response from the companies and on the verification of evidence of the CE practices by the author. For example, some assessed items were eliminated because they were not found critical while building the knowledge base and they were confusing for the respondents (e.g. Use of 'fuzzy gates'). Other items were either rephrased or reference comments were added in order to reduce their ambiguity (e.g. Use of carry-over design practices). New items were added because they were perceived to be highly important by NPD executives (e.g. Streamlining the NPD process). After conducting the case studies some 'minimum answers' were recalibrated. For example, the maturity chart of the element of *Design Tools and Techniques* for Case Study 1 showed that neither *Design for Manufacture*

(DFM) nor *Rapid Prototyping* were in place. However, after the author asked for evidence on the use of these practices, he found that the company applied these techniques. However, the CETGI software considered these practices as absent because eighty percent of the respondents considered a 'little' use of *Rapid Prototyping* and all the respondents considered that there was a 'partial' use of DFM. Therefore, the author calibrated the minimum answer of Rapid Prototyping to the value of two ('little' or 'rarely') and that of DFM to the value of three ('partially' or 'casually'). Initially, all the practices with a five-point Likert scale ('not at all' to 'completely', or 'never' to 'all the time') had a minimum answer of four ('generally' or 'most of the time').

Chapter 6

VALIDATION THROUGH INDUSTRIAL APPLICATION

The author used CETGI in three industrial case studies, aiming to assess its reliability, validity[10] and industrial usefulness. Submission 10 describes task by task, the assessment process conducted in these case studies (including their outputs) and Submission 7 presents the validation work. This chapter presents an introduction to the case studies and highlights the main validation results.

6.1 Industrial Application of CETGI

The three case studies were conducted to first tier suppliers, two of the automotive and one of the transport industry:

- Case Study 1 develops and manufactures automotive steering columns and has a turnover of £ 73 M (1999). The company has European and 'transplant' projects, which are mostly designed in Japan and manufactured in the UK, requiring some additional design work to be done by the company. Case Study 1 is currently owned by a Japanese group with a turnover of £ 2.4 billion (1999), specialised in the integration of motion and control products.

- Case Study 2 develops and manufactures fluid systems (pumps) for various OEMs including automotive (major customers), motorcycle and recreational product companies. The company has a turnover of £ 38 M (1999) and belongs to an American group with a turnover of £ 8.8 billion (1999). Case Study 2 interacts with two business units of its parent group: an engine systems group based in Germany (including products such as seals, gaskets and bearings) and an electronics group based in the USA.
- Case Study 3 develops and manufactures brake systems for trailers and trucks. This company had a turnover of £ 27.3 M in 1999 and belongs to a Swedish group with a turnover of £ 500 M (1999). Case Study 3 interacts with American and German product centres of its parent company.

The NPD executives of these Case Studies used the CETGI tool in order to assess improvement opportunities of both their local NPD capability and their capability to develop products in collaboration with other NPD centres of their parent companies. Two of these Case Studies contacted the author after receiving the 'CETGI Marketing Document' (Submission 11). Because the CETGI tool evolved through the project execution (See Submission 7), different response methods were applied (See Submissions 7 and 10): personal interviews were conducted during Case Study 1, using the CETGI questionnaire based on Excel Macros©; Case Study 2 used the

[10] Hussey and Hussey (1997) define reliability as: - "*The extent of repeatability of the research findings*", and validity as: - "*The extent to which the research findings accurately represent what is really happening in the situation*"

Internet enabled software without using its remote data acquisition capability (personal interviews were used); Case Study 3 also used the Internet enabled software with 62% of the participants responding remotely to the CETGI questionnaire. The same process was used in the other assessment tasks.

6.2 Validation of CETGI

In relation to its usefulness, the author evaluated the perceived contribution of the tool output by the NPD executives in terms of the appropriateness of the prioritised suggested actions and the estimated impact of these actions on NPD performance. After benchmarking current CE assessment tools the author found that only De Graaf (1996) conducted industrial validation work as part of the development of RACE II within his PhD (Submission 7 explains this validation work). In order to validate CETGI, the author decided to use similar metrics to those used by De Graaf together with additional quantitative techniques defining specific metrics. Table 12 presents a summary of these metrics, which are compared and contrasted for all Case Studies (Submission 7 describes these metrics in greater detail). Table 13 presents a summary comparison of the validation metrics for the three industrial Case Studies. Various observations are made:

- The NPD executives of all the participating companies identified at least 43% of the suggested actions as new contributions from CETGI. Triggering new actions through the knowledge base was considered useful by NPD executives.
- On average, one quarter of the total number of actions suggested had a global nature, strengthening the collaboration between distributed NPD teams.

CRITERIA	METRICS USED	SOURCE
Level of team awareness and cooperation to the assessment.	- Percentage of questionnaires completed and returned on time. - Percentage of attendance at the consensus sessions.	De Graaf (1996)
Time spent in the assessment	- Number of man hours spent	Used by most of the CE assessment tools
Level of adequacy of the prioritised actions suggested	- Percentage of actions considered appropriate to the assessed companies (by the NPD executives).	Created by the author
Extent of contribution with new actions, not previously considered	- Percentage of actions considered appropriate and not previously considered.	Created by the author
Global Nature of Actions	- Percentage of global NPD actions considered appropriate	Created by the author
Level of deployment decision	- Percentage of actions selected for implementation - Percentage of actions 'really' implemented	Created by the author
Reliability of questionnaire responses	- Correlation coefficient, obtained from the 'split-halves' and the 'test re-test' methods. - Ranges and standard deviations of responses, to compare the different perceptions on the assessed items.	Hussey and Hussey (1997)
Level of perceived usefulness	- Participants' feedback based on their own statements and rating questions, on a ten-point Likert scale.	Feedback form created by the author
Performance impact	- In terms of the estimated long-term impact in the reduction of time to market, product unit cost and project expenses, and the improvements of quality.	Estimated by the product development executives

Table 12. Validation Metrics used in CETGI

Metric Used	Case Study 1	Case Study 2	Case Study 3
Total Time (Man-Hours)	91 hrs	12 hrs	107 hrs
Cooperation to the Assessment			
Number of Participants	28	3	23
Number of Participants Responding to the CETGI Questionnaire	25	2	23
Percentage of questionnaire completed and returned on time	100%	100%	86% response rate and 84% completed on time
Questionnaire Reliability			
Reliability Index Satisfactory?	YES	YES (Repeatability, proved with the 'test-re-test' method)	YES (for the three responding methods)
Adequacy of Actions			
Percentage of Actions Suggested Considered Appropriate[11]	93 % (from 70 actions)	65 % (from 54 actions)	86 % (from 70 actions)
Percentage of Actions Suggested Considered as a New Contribution from CETGI	50 % (from 70 actions)	43 % (from 54 actions)	43 % (from 70 actions)
Percentage of 'Global' Actions Suggested Considered Appropriate	23 % (from 70 actions)	26 % (from 54 actions)	26 % (from 70 actions)
Percentage of Scenario Changes Considered Appropriate	57 % (from 7 actions)	67 % fully appropriate 33 % partially appropriate (from 3 actions)	88 % for Scenario 1 (from 8 actions) 83 % for Scenario 2 (from 6 actions)
Deployment Decision			
Percentage of Actions Suggested Selected for Implementation	53 % (from 70 actions)	48 % (from 54 actions)	83 % (from 70 actions)
Percentage of Actions Implemented	51 % (from 37 selected actions)	On going	On going
Estimated Performance Impact			
	17% reduction in development time (5 months out of 30) 1% to 5 % reduction of product unit costs	8 % reduction in time to market (eliminating 50% of the current delays) 5 % reduction of product unit costs	20% to 40% reduction in time to market A minimum of 15% reduction in product unit costs

Table 13. Summary Comparison for the CETGI Validation Metrics

[11] Percentages based on the total number of initial actions suggested

Metric Used	Case Study 1	Case Study 2	Case Study 3
Perceived Usefulness			
Identifying bottlenecks and improvement opportunities	8 (0)[12]	7.5 (0.7071)	7.5 (0.58)
Selecting and prioritising the improvement actions	8 (1.414)	7 (0)	8 (1.414)
Providing a new perspective of the current product development process	7 (1.414)	6.5 (0.7071)	7.75 (0.957)
Providing an overall picture of the current product development process	7.25 (0.5)	8 (0)	8.25 (0.5)
Structuring and aggregating the individual view of the employees about the product development process	8.5 (0.58)	7 (1.414)	7.75 (1.258)
Promoting global product development	7.5 (0.58)	8 (0.7071)	8.25 (0.5)

Table 13. Summary Comparison for the CETGI Validation Metrics (2 of 2)

- On average, the NPD executives considered appropriate 74% of the changes suggested by the scenario analyses, mostly because the other changes involved practices already in place.
- On average, 61% of the actions initially suggested were selected for implementation. Case Study 3 decided to implement 83% of the actions. The latter company was also highly committed to the assessment and had already initiated the implementation of some actions in a critical on-going project.
- In terms of the performance impact from the actions suggested by CETGI, on average, it was estimated an 18% reduction in time-to-market and an 8%

[12] Standard deviations

reduction in product-unit costs. None of the companies assessed estimated quality improvements or reduction in project expenses.

- All the CETGI questionnaire response methods were found to be reliable, including the Internet based assessment. However, the response rate from using the Internet compared to that from having the facilitator support reduced by 14%.
- In terms of the perceived usefulness of CETGI, promoting GCE was rated the highest, followed by providing an overall picture of the current NPD process. Providing a new perspective of the current NPD process was rated as having the lowest usefulness. The NPD executives of the companies assessed appreciated having a concise list of actions easy to be managed and considered that without the use of the tool, some actions could have been overlooked (See comments of executives presented in Submission 7).
- The greater the number of respondents to the CETGI questionnaire, the greater the number of prioritised actions suggested were considered appropriate. As highlighted in Submission 10, there were various practices identified as absent by the CETGI software within Case Study 2 because one of the two respondents responded below the 'minimum answer' (e.g. 'generally' or 'yes') established, not satisfying the assessment criteria of a minimum of two thirds of the responses being equal or above the 'minimum answer'. Increasing the number of participants significantly increased the percentage of appropriate actions suggested to over 85%.

Chapter 7

DISCUSSION

7.1 Theoretical Basis of CETGI

Three main knowledge areas have contributed to the development of the CETGI tool: *basic and global product development best practice studies* ('INTERPROD' (Submission 8 plus Submissions 2, 3 and 4); *current CE assessment tools* (Submission 5) and basic theory on *Group Decision Support Systems* (GDSS) and *Multiparticipant Decision Making* (MDM) (Submission 6). It is important to point-out that the CETGI tool does not claim to be an 'expert system', as the latter has the capability to explain its conclusions (Goodall, 1995) and the basis for the decisions suggested (Shortliffe and Fagan, 1982). CETGI is an assessment tool, a benchmarking tool and a GDSS: CETGI translates qualitative information into a quantitative form by aggregating the participant answers and evaluating the response of the majority. Some of the CETGI tasks are based on additional knowledge fields, for example the management consensus session has been designed, based on the *Nominal Group Technique* (NGT) developed by Delbecq et al., (1975), and the *cost-benefit analysis* is based on basic financial decision-making concepts (Johnson, 1970; Michales et al., 1989; Price, 1993; and Lumby, 1995).

7.2 The Novel Features of CETGI

The CETGI tool provides the following novel contributions:

I. The tool has embedded the findings of various product development best practice studies, some of which were partly (e.g. 'INTERPROD', Submission 8) or fully conducted by the author ('1998 Global NPD Survey', Submission 2; 'Case Studies on GCE', Submission 4), or conducted by a third party (Kahn and McDonough, 1996; Hauptman and Hirji, 1999; Cooper and Kleinschmidt, 1993; Rothwell, 1985). The author stresses that some of the previous studies lack statistical robustness (e.g. 'Case Studies on GCE' and Kahn and McDonough, 1996) and that some of the items of CETGI have been defined based on the literature. Therefore, the advice provided by CETGI is suggestive rather than conclusive, and the author suggests that industrial calibration iterations should be conducted on a continuous basis, reducing the above limitations (Submission 7 describes two evolution iterations). The author selected this pragmatic approach, after facing similar difficulties to those faced by Clark and Fujimoto (1991) when assessing international product development. The previous authors emphasised the data acquisition problems they faced when investigating product development practice in the automotive industry in Europe, USA and Japan. They highlighted the need to collect field data and the related problems of information confidentiality and differences in technical vocabulary. Finally, Clark and Fujimoto (1991) comment about the complexity of the study because of its international and interdisciplinary approach. Nevertheless, CETGI has a greater level of industrial backing than the current CE assessment tools, mostly empirically based (Submission 5). In addition, unlike the other tools, CETGI has a global focus.

II. The CETGI assessment process learned from the RACE process (De Graaf, 1996): having a pre-defined questionnaire answered by a multifunctional cross-section of product development individuals, the results of which are reviewed in a consensus session, defining specific improvement actions. Nevertheless, there are various differences, from the RACE process, which have been introduced in order to satisfy the CETGI requirements:

i. Upfront work was conducted, determining critical success factors for GCE, which were embedded in the knowledge base, as weights are allocated to each questionnaire item, facilitating the action prioritisation process.

ii. The CETGI knowledge base contains pre-defined decision rules allowing the customisation and prioritisation of actions suggested to the participant companies, reducing the time and resources required for the assessment.

iii. CETGI has the capability to capture participants' comments, which are then represented through the 'Voice Of the Company' (VOC) diagrams, supporting company specific improvements.

iv. RACE defines the business drivers through extensive discussion with management, assessing the impact of actions on these business drivers case by case (Submission 5). The author conducted sessions to define business drivers with the first case company, finding that it was time-consuming, effort-intensive and that the final results were biased, as some participants were more dominant than others. Therefore, CETGI assesses the business drivers at a top level, using the 'case profile', facilitating the selection of actions.

v. The use of a *cost-benefit analysis* has been introduced into the CETGI assessment process, strengthening the decision-making quality of the actions selected through a quantitative analysis.

vi. The RACE maturity radar chart only positions a company on each of the assessed elements without showing partial levels of maturity. After assessing some companies, the author observed that they might have implemented some actions of the next maturity level while still have not fully implemented some actions of the level below. Therefore, it was considered valuable to use the colour coding for the CETGI maturity chart, this being more meaningful as it illustrates partial levels of maturity. However, one of the NPD executives suggested using the RACE chart in parallel as it uses a 'go no-go' criterion, showing a unique maturity level.

vii. Finally, CETGI has the capability to conduct *scenario analysis* assessing the sensitivity of companies to having specific practices, based on their profile. This analysis is suggestive rather than conclusive, as not all the relations established are statistically valid. Therefore, as cautionary measure, the enabler priorities are defined based on the worst-case, by selecting the maximum priority from the 'differentiating attributes' affected.

III. CETGI has an improved *benchmarking capability* over other CE assessment tools, as increased visibility is provided, showing partial levels of maturity and its software structure allows the user to select the product development centre and company, for which (s)he wants to conduct the analysis. In addition, the capability of remote data acquisition and results' generation facilitates the analysis of the assessment. Therefore, the latter promotes the use of the CETGI tool by more companies. However, some of the respondents to the CETGI questionnaire who used the Internet experienced some delays.

IV. CETGI has the capability of remote data acquisition and results generation. This capability has been partly validated being used by 62% of the respondents of Case Study 3, finding similar reliability with regard to the face-to-face questionnaire. Prior to using the tool remotely, the author explained to all the respondents in a face-to-face situation, how to answer the questionnaire (see Submissions 7 and 10). The use of video-conferencing, suggested as an alternative communication resource in Submission 6, has to be tested.

7.3 Satisfying the Requirements of CETGI

Appendix 8 presents a comparative matrix relating each of the requirements defined for the CETGI assessment tool to each of the tools compared, including CETGI. CETGI has satisfied most of its *must* requirements:

➢ In terms of the *musts* of the **assessment method:**

- *Multifunctional participation* was promoted through two assessment phases: the automated questionnaire and the management consensus sessions,
- *Decision-makers involvement* was promoted through the kick-off, the preliminary interview, and the management consensus sessions,
- *Ambiguity* was reduced by providing reference explanation to the assessed items of the automated questionnaire, by including an on-line glossary describing the CETGI terminology, and by asking for specific evidence (e.g. documents or physical evidence) validating the items assessed,

- *Standard conditions* were promoted through the inclusion of guidelines for the preliminary interview and the questionnaire answering process (e.g. type of respondents that should participate and areas that should cover),
- *Upgradability* was provided as the CETGI knowledge base is easy to upgrade and maintain as it is contained in a modular database, and guidelines are given facilitating the maintainability process (e.g. using different revisions for each version of CETGI).

➢ In terms of the *musts* of the **assessment elements:**

- *Relevance to GCE* and the *inclusion of basic CE practices* were promoted through embedding the best practices that were found in the author's own industrial studies and in the current literature review.
- *Clarity of dimensions and scales* was promoted through the definition of a hierarchy of dimensions, elements, sub-elements and items,

➢ In terms of the *musts* of its **final output:**

- *Company specific improvements and action prioritisation support* were partly promoted through the algorithm that generates the list of customized prioritised actions. Therefore, the use of the 'VOC' diagrams, the cost-benefit analysis and the management consensus sessions were included, customising the final actions to the company assessed.
- Including a *performance perspective* was promoted through the inclusion of maturity charts, showing the percentage of implemented actions on each of the

assessed elements and on each maturity level, highlighting improvement opportunities.

Compared to the other tools, in terms of its *wants*, within the assessment output, the CETGI tool satisfied highly the output visibility and the automatic feedback to participants and within the assessment elements, CETGI is the only tool with industrial backing because of the previous industrial research conducted towards its development (See Appendix 8).

7.4 Comparison of Validation Results

The author compared the validation results of CETGI with those of RACE II, the only tool in which validation work was conducted (De Graaf, 1996). De Graaf gave no evidence about the reliability of the RACE II questionnaire nor about its estimated impact in performance. In terms of the metrics available, there were no major differences between the two assessment tools. The metrics on the deployment decision, which are critical for the assessment tools, are difficult to be compared and De Graaf did not provide detailed information in terms of the actions selected for implementation. De Graaf re-assessed one of the companies eighteen months after the first assessment, finding that overall, 17 criteria were rated higher than the first assessment, from which only two were indicated in that assessment as desired. As part of the CETGI project, a post-assessment review was conducted on Case Study 1 with similar results to those of De Graaf's re-assessed case: only 51% of the selected actions were implemented.

7.5 Additional Lessons Learned

Various other lessons were learned from the CETGI project:

- *Top management support* is critical for the success of the CETGI assessment process. As explained in Submission 10, a higher percentage of actions was selected for implementation in those companies where top management supported the process. In addition, as found during the post-assessment review of Case Study 1 and the RACE re-assessed case: leadership, ownership and close monitoring are critical to the successful deployment of actions and the management of change.
- With regard to its potential applications, CETGI could be applied across the *supply chain* of global corporations and it could be customised to their specific needs so that they could assess whether a minimum NPD capability is present and they could recommend specific actions to their suppliers (read Submission 7). Submission 4 suggested that CETGI could also facilitate the integration and cross-fertilisation of NPD units either in *global restructuring* or during the due diligence phase of a *merger and acquisition* process assessing the level of fit in terms of the NPD capabilities of the companies involved and suggesting areas where companies could learn from each other.

Chapter 8

CONCLUSIONS

The collaboration of multi-functional distributed teams working in NPD projects, called global new product development (GNPD), has been promoted because of the globalisation of industrial activities and the increased product complexity. GNPD offers various industrial benefits such as facilitating the transfer of engineering know-how to manufacturing facilities and the product adaptation to local markets. However, there are many industrial experiences of under performing GNPD teams such as the development of the Think Pad© by IBM and the Contour/Mondeo by Ford. Therefore, the need was identified to support companies when conducting GNPD. The development of a Global Concurrent Engineering (GCE) assessment tool was identified as a potential solution to the research problem, as it can encapsulate best practices and advise companies. Therefore, the EngD project CETGI (Concurrent Engineering and Teamwork across Global Industries) was conducted to develop this tool.

There were four major project phases: preliminary investigation, development of the CETGI tool, validation of the tool through its industrial application and delivery of the tool. The preliminary investigation included a review of previous studies on the success factors of new product development (NPD) and the author's own studies exploring in further detail GCE combining a qualitative and a quantitative approach.

Similar to previous studies (Kahn and McDonough, 1996; Hauptman and Hirji, 1999), 'soft' factors (or people related) were found more critical to success than 'hard' factors (design tools and information technology). Within the 'Case Studies on GCE' (Submission 4), the author compared the GCE practices of high performing and low performing teams, of fast development and slow development teams and of complex and non complex projects.

Research revealed nine current CE assessment tools which were compared in terms of their assessment method, their assessment elements (or areas of NPD covered) and the output they gave to the participant companies. The strengths and weaknesses of each tool were identified for use in the CETGI tool and the requirements of the tool were defined. Multifunctional participation, decision makers' involvement, replication, relevance to GCE, the inclusion of basic CE practices, the clarity of dimensions and scales, providing company specific improvements, supporting action prioritisation and the provision of a performance perspective were identified as *musts* for the CETGI tool. Therefore, a similar assessment method to that used in the RACE II tool (De Graaf, 1996) was selected because RACE II contains relevant product engineering and information technology elements, includes a performance perspective, has a multifunctional nature and high level of employee involvement. However, additional novel features were required in order to provide customised advice to the assessed companies and to satisfy the *musts* of the CETGI tool: these were embedding the findings from the preliminary investigation of the CETGI project in a knowledge base, defining 'Voice of the Company' (VOC) diagrams, developing an Internet enabled software that supports multiparticipant decision making, introducing a cost-benefit analysis as part of the assessment process, increasing the visibility of improvement opportunities through the use of the traffic light system in the maturity charts illustrating partial levels of maturity, including the capability of scenario analysis and improving the benchmarking capability of the tool by the use of structured software with remote data acquisition capability.

In order to fine-tune and validate the CETGI tool, it was applied in three first tier supplier companies, two from the automotive industry and one from the transport industry. These companies were based in the UK with their parent companies in the USA, Sweden and Japan. The definition of validation metrics for the CETGI tool was based on those used in current CE assessment tools and on its own metrics defined by the author including reliability, validity and industrial usefulness. With regard to the reliability of the CETGI questionnaire, after applying the split-halves method (Hussey and Hussey, 1997), all responding methods were found to be reliable. With regard to the validity of the CETGI tool, about 90% of the actions advised to the companies were considered appropriate, about 70% were selected for implementation and about 50% have already been implemented (based on the selected actions in Case Study 1). About 25% of the total actions suggested and considered appropriate had a global nature and about 50% of the total actions suggested were considered as new contributions to the actions previously considered by the NPD executives of the assessed companies. These executives estimated that the actions advised reduced time-to-market and product-unit costs. With regard to its perceived usefulness, CETGI was rated highest in terms of promoting global product development, and next in providing an overall picture of the current product development process.

Some examples of the variety of the world best practices have been listed, however, it was not the task of this project to analyse these. Based on a variety of sources, the best practices embedded in the CETGI tool have been used to assess a number of companies.

In conclusion, this EngD project has delivered a GCE assessment tool with various novel features, which has been applied successfully in three companies, satisfying the initially established objectives.

Chapter 9

FURTHER WORK

Further work opportunities have been identified in three main areas: developing specific versions of the tool, embedding additional comparative data in the knowledge base and improving the CETGI software.

9.1 Developing Specific Versions of the Tool

The CETGI assessment tool has only been validated and evolved through its application in three companies, two from the automotive and one from the transport industry. As described in Submissions 2, 4 and 8 ('INTERPROD' papers), electronics and aerospace companies are substantially different in terms of the product life cycles, the product technologies and the design tools and techniques they require, also software development is often critical for their products. Hence, the CETGI tool should be applied in these industrial sectors evolving and customising the knowledge base. The CETGI assessment process and its support software have been designed using a relational database so that the knowledge base can be easily upgraded. Therefore, the same process and software can be used. The author also suggests that additional research must be conducted in order to identify and confirm the critical GCE practices in these industries.

9.2 Embedding Additional Comparative Data

Although the tool has been developed by assessing best practices, a baseline for comparison needs to be developed using *world-class* companies. Having this baseline will increase the value of the assessment.

The three companies where the CETGI tool has been used are based in the UK with their parent companies in the USA, Sweden and Japan. The author suggests that the tool is used in other countries apart from the UK, in order to examine any cultural implications in the assessment. For example, evaluating whether the actions considered appropriate in the UK differ and whether using the Internet as a responding method to the CETGI questionnaire has significant differences in terms of its reliability index (See Submission 7). The latter would require developing multilingual versions of the tool.

9.3 Improving the CETGI Software

After using the CETGI software in the three Case Studies, the following improvement opportunities were identified:

- The CETGI software could be evolved from a multiparticipant decision making to an *expert system* with the capability to explain the basis for the actions suggested (Goodall, 1995; Shortliffe and Fagan, 1982). This would require an algorithm to trace back the reasons of each action by looking their 'priority ranks', the levels of the 'differentiating attributes' in the 'case profile' and the practices implemented.

- To develop a *quick answering* option, so that rather than answering sub-element by sub-element submitting the individual answers to the assessed items, all the questionnaire items could be responded on the same screen and their results submitted at once. This improvement was suggested by one of the respondents from Case Study 3.
- To develop a user-friendly capability in order to *initialise the data* required for the assessment: the case profile, the user information and the selected NPD centre.
- To include *automated filters* so that the assessed questions are addressed to the appropriate respondents in a company (Hague, 1994).
- To *link dependent items* so that if a company lacks a 'basic' practice, dependent items would not be asked. For example, if a company does not have CAD, there is no point of including additional items assessing CAD practices further.

An additional research opportunity would be to use the CETGI tool to assess other business areas apart from GCE. This would require conducting upfront work investigating best practices in these business areas and embedding the results in specific knowledge bases. The assessment method, the structure of the knowledge base, the software and the analytical algorithms would remain the same.

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APPENDICES

	Company												
	HP	Raychem	NEC	Ricoh	Toshiba	Ericsson	Rover	Dana	Meritor	Borg Warner	GKN	Airbus	J&J
Complexity Criteria (*)													
1. Supplier Co-ordination	4	4	3	4	3.5	2	7	3	3	4	3	7	6
2. Product Modules	7	5	4	5	5	4	5	4	3	4	1	7	4
3. Product Configuration	4	3	6	7	5	4	4	5	2	4	1	7	2
4. Product Technologies	7	5	7	2	7	6	1	3	2	6	1	7	7
5. Manufacturing Technologies	7	3	5	2	2.5	6	1	1	2	5	4	5	6
Complexity Index (Total)	29	20	25	20	23	22	18	16	12	23	10	33	25
Cluster (Index / 5)	6	4	5	4	5	4	3	3	2	5	2	7	5

(*) Complexity Criteria

	Values for Complexity		
	1 Not Complex at all	4 Somewhat complex	7 Very complex
1=	In-house development	Up to 5 core suppliers	More than 20 suppliers
2=	Only one module	Up to 3 modules	More than 10 modules
3=	Lack of critical interfaces	Up to 5 critical interfaces	More than 10 critical interfaces
4=	No new technologies	Up to 3 new core technologies	More than 5 new core technolog
5=	No new technologies	Up to 3 new core technologies	More than 5 new core technolog

	Company												
Complexity Criteria	HP	Raychem	NEC	Ricoh	Toshiba	Ericsson	Rover	Dana	Meritor	Borg Warner	GKN	Airbus	J&J
No. NPD Centres	2	3	2	2	3	3	2	2	3	2	2	4	3
Interaction between centres (**)	6	3	3	2	5	3	2	3	4	3	2	7	3

(**) Index of interaction between centres which developed the product:

1= Only one centre
2= Two centres with one of them contributing with more than 80% of the eng. Hrs
3= Two centres with one of them contributing simultaneously with more than 50% of the eng. Hrs
(A third centre might be involved in a later phase)
4= Three or more centres with one of them contributing simultaneously with more than 80% of the eng. Hrs
5= Three or more centres, one of them contributing simultaneously with more than 50% and less than 80% of the eng. Hrs
6= Two centres contributing simultaneously with similar % of eng. Hours
7= Three or more centres contributing simulataneously with similar % of eng. Hours

Appendix 1. Calculation of Indexes of Product Complexity and Interaction between NPD Centres

Explanatory Note: These indexes were defined in order to compare the use of enabling practices in distributed teams, as part of the GCE Case Studies. For each product developed on the case studies, five product complexity categories were evaluated (see top table), then these were added and divided by five to form seven clusters. The index of interaction between centres was calculated based on the level of contribution and overlapping of activities between all development centres (see bottom table).

Comparison Criteria \ TOOL	Mentor Graphics	RACE	McGrath Maturity Model	SEGAPAN	RACE II
Assessment (A) or Implement Fmwk (IF)	A	A	A	A	A
Self-assessment	Yes	No	Yes	Yes	No
Automated	No	No	No	Yes	No
Multiple sources of data	No	Yes	No	No	Yes
Number of respondents (or participants)	One minimum	Min 15	One minimum	One	Min 15
Level of interaction with decision makers	Medium	High	Low	Low	High
Assessment time	Min 1 Hr	65 Man Hrs (Two weeks) - One assessor	Min 30 min	One day	Two weeks - Two assessors
Total number of questions (if applicable)	83 + Methods matrix	130 (70 for process and 60 for technology)	64 (16 categories at 4 levels)	302 (Grouped into five areas)	131 (71 for process and 60 for technology)
Replication	Low	Medium	Low	Medium	High
User friendliness	High in input, medium in output	Low	Medium	Medium in input, high in output	Low

Comparison Criteria \ TOOL	BRACE	PACE	5X5 Framework	Cranfield Tool
Assessment (A) or Implement Fmwk (IF)	A	Both	Both	IF
Self-assessment	No	Yes	Yes	Yes
Automated	No	Yes	No	No
Multiple sources of data	Yes	Yes	Yes	Yes
Number of respondents (or participants)	Min 15	Not specified - only that a large number is suggested	Min one: the champion of change	One internal facilitator plus additional participants
Level of interaction with decision makers	High	High - It includes a CEO questionnaire	High	High
Assessment time	Two weeks	Not specified	Continuous process	Continuous process
Total number of questions (if applicable)	Not available (16 elements grouped into two categories: process and technology)	180	Five disciplines at five levels with an average of three goals and 10 activities per combination	Not applicable
Replication	Medium	Medium	Medium	Medium
User friendliness	Low	Medium	Medium	Medium

Appendix 2. Comparison of CE Assessment Methods

Explanatory Note: Nine current CE assessment tools were found and compared (see Submission 5). This appendix shows the comparison of their assessment methods. Appendix 3 compares the assessment elements and Appendix 4 compares the generated output of the tools.

	Mentor Graphics	RACE	McGrath Maturity Model	SEGAPAN	RACE II
Elements					
Project Organisational Structure	No	No	No	Yes	No
Teamwork	Yes	Yes	Yes - Not in detail	Yes	Yes
Co-ordination and Integration Mechanisms	No	Partly - Only at the product level	No	Partly	Partly - Only at the product level
Project Management	Partly: Section of planning included	Partly - Within the mgt systems process element	Yes - Not in detail. Performance measurement covered	Partly	Yes - Within the mgt systems process element
Product Development Process	Partly: Design methodologies and validation of process covered	Partly	Yes - Not in detail	No	Partly
Product Engineering	Partly: Design standards and component engineering covered	Partly	Partly: Design standards covered, not in detail	Partly	Yes - It added to RACE a product architecture element
Use of Information Technology					
Communication	Partly: E-mail covered / VC not	Yes	No	Yes	Yes
Administration	No	Yes	No	No	Yes
Engineering Design	No	Yes	No	Yes	Yes
Data Management	Partly	Yes	No	Yes	Yes
Engineering Tools (Simulation / VR)	Partly: Optimisation section looks at some aspects	No	No	Yes	No
Decision Support Tools	No	Yes: Within application tools	No	No	Yes: Within application tools
GroupWare	No	Partly: Within information sharing and co-ordination	No	No	Partly: Within information sharing and co-ordination
Use of Design Tools and Techniques	Partly: Some questions address the use of DFM and customer requirements' capture.	Partly	Yes - Not in detail	Yes	Partly
Other Elements Covered	None	Leadership	Technology planning and Strategic Vendor Alliances	Supplier's involvement, group technology and cultural change	Product Architecture and Strategy Deployment
Basis for the element selection					
Literature Review	Yes	Yes	Yes	Yes	Yes
Industrial Surveys	No	No	No	No	No
Implementation Work	Yes	No	Partly	No	Yes
Experience from creators	Yes	Partly	Yes	No	Partly
Statistical significance proved?	No	No	No	No	No
Are the elements of this tool sufficient for CETGI?	No	No	No	No	Partly
Does the tool have a consistent element categorisation?	Partly	Yes	Partly	Partly	Yes
Does each element cover the whole maturity continuum?	Yes (inconsistently)	Yes	Yes	Maturity not used	Yes
Is cost of implementing actions considered?	No	No	No	No	No
Implementation guidelines provided?	Not specifically - General book	No	Not specifically - General book	No	No

Appendix 3. Comparison of CE Assessment Elements

Comparison Criteria \ TOOL	BRACE	PACE *	5X5 Framework	Cranfield Tool
Elements				
Project Organisational Structure	No	Partly	No	No
Teamwork	Yes	Yes	Yes	Yes
Co-ordination and Integration Mechanisms	Partly - Only at the product level	Partly	Partly	No
Project Management	Partly - Within the mgt systems process element	Partly	Yes	Partly - Project planning guidelines provided
Product Development Process	Partly	No	Partly - Within phase review core practice under the process mgt discipline	No
Product Engineering	Partly	No	Partly- Within platform and reuse, and product planning core practices	No
Use of Information Technology				
Communication	Yes	Partly	No	No
Administration	Yes	Partly	No	No
Engineering Design	Yes	Partly	No	No
Data Management	Yes	Partly	No	No
Engineering Tools (Simulation / VR)	No	No	No	No
Decision Support Tools	Yes: Within application tools	No	No	No
GroupWare	Partly: Within information sharing and co-ordination	No	No	No
Use of Design Tools and Techniques	Partly	Partly	Partly	No
Other Elements Covered	Innovative climate and organisational value analysis	Not relevant to mention	Process change management / technology mgt / Work product mgt	Guidelines to develop a cost model
Basis for the element selection				
Literature Review	Yes	Yes	Yes	Yes
Industrial Surveys	No	No	No	Yes
Implementation Work	Partly	No	Partly	Partly
Experience from creators	Partly	Partly	Yes	Partly
Statistical significance proved?	No	No	No	Partly
Are the elements of this tool sufficient for CETGI?	No	No	No	No
Does the tool have a consistent element categorisation?	Yes	Partly	Yes	Not applicable
Does each element cover the whole maturity continuum?	Yes	Maturity not used	Yes	Maturity not used
Is cost of implementing actions considered?	No	Yes - Isolated from assessment	No	Partly - Only as a guideline
Implementation guidelines provided?	Partly - Based on change mgt	Yes - Isolated from assessment	Yes	Yes - Tool is an implementation resource

Appendix 3. Comparison of CE Assessment Elements (2 of 2)

Comparison Criteria \ TOOL	Mentor Graphics	RACE	McGrath Maturity Model	SEGAPAN	RACE II
Company specific improvements	Yes - customised by the user	Yes - customised by the user	No	Yes - customised by the user	Yes - customised by the user
Support for the action priorisation	Yes	Yes	No	Yes	Yes
Performance perspective	Yes - Lacks of clarity	Yes - More clear than previous	Yes	No - Only raw scores given per practice	Yes - Same as RACE
Benchmarking capability	No	No	No	Yes	No
Graphical output	Yes	Yes	No	Yes	Yes

Comparison Criteria \ TOOL	BRACE	PACE	5X5 Framework	Cranfield Tool
Company specific improvements	Yes - customised by the user	Yes - customised by the user	Yes - customised by the user	Yes - customised by the user
Support for the action priorisation	Yes	No	Yes	Only guidelines
Performance perspective	Yes - Same as RACE	Yes - Comparing actual versus target practices	Yes - Similar levels to RACE	No
Benchmarking capability	No	No	No	No
Graphical output	Yes	Yes	No	No

Appendix 4. Comparison of the Final Output of the CE Assessment Tools

The Assessment Method

Musts	*Tool where CETGI could learn*	Wants	*Tool where CETGI could learn*	Bonuses	*Tool where CETGI could learn*
Multifunctional participation	RACE and its derivatives fully. Partly the other tools.	User friendliness	Partly Mentor Graphics and SEGAPAN.	Low time and organisational resources involved	Mentor Graphics, Mc Grath maturity model and SEGAPAN
Decision-makers involvement	RACE and its derivatives fully. Partly the other tools.	Easy access	Partly all the tools	Self-assessment capability	Mentor Graphics, Mc Grath maturity model, SEGAPAN, PACE, 5X5 Framework and the Cranfield tool
Low ambiguity	RACE II and SEGAPAN	Benchmarking capability	SEGAPAN	Multilingual capability	None of the tools
Standard conditions	RACE and its derivatives, Mentor Graphics, and SEGAPAN	Implementation guidelines	5X5 Framework and Cranfield tool		
Upgradability	SEGAPAN fully, partly Mentor Graphics, RACE and its derivatives	Virtual assessment capability	None of the tools		

The Assessment Elements

Musts	*Tool where CETGI could learn*	Wants	*Tool where CETGI could learn*	Bonuses	*Tool where CETGI could learn*
Relevance to Global Concurrent Engineering	Partly RACE II	Industrial examples provided	Cranfield tool and PACE.	Balanced model	Mentor Graphics, partly SEGAPAN and RACE derivatives.
Clarity of dimensions and scales	RACE II and its derivatives. Partly Mentor Graphics.	Industrial backing	Cranfield tool	Low number of elements	McGrath maturity model
Inclusion of basic CE practices	Most of the tools			Statistical backing	Partly Cranfield tool

The Assessment Output

Musts	*Tool where CETGI could learn*	Wants	*Tool where CETGI could learn*	Bonuses	*Tool where CETGI could learn*
Company specific improvements	Partly Mentor Graphics and RACE. They both require user customisation.	Output visibility	Mentor Graphics, RACE and SEGAPAN.	Automatic feedback to participants	SEGAPAN
Action prioritisation support	Partly Mentor Graphics and RACE.	Scenario evaluation	None of the tools has this capability		
Including a performance perspective	RACE and its derivatives, and the 5X5 Framework.				

Appendix 5. Requirements' Definition for the CETGI Assessment Tool

Explanatory Note: This appendix defines the requirements for the CETGI Tool, categorised as *musts, wants* and *bonuses* based on the benchmark of current concurrent engineering tools. The appendix also illustrates the tools particularly strong on each requirement. Read Submission 5 for further detail on how each requirement was defined.

Elements		SOURCES: Stat. Sign.	Ranked highly imp	Literature	INTERPROD	1998 GNPD Survey	GNPD Case Studies	Other CE Assess. Tools	Expert Feedback	Tool Application
Project Organisational Structure	Definition	N		Stickley (1994), Cleland (1994), Koehler (1992), Gassman et al., (1996)				SEGAPAN		
	Monitoring	N	Y	Stickley (1994), Cleland (1994)	X					
	Fit to Project	N		Wheelwright and Clark (1992), Clark and Fujimoto (1991), Clark (1995), Kolodny (1980)		X				
	Integration	N								
	Hierarchy	N		Katzenbach and Smith (1993)						
	Agility	N								
Teamwork	Purpose Awareness	Y	Y	Kahn and McDonough (1997), Katzenbach and Smith (1993)	X					
	Top Management Involvement	Y			X					
	Core top level team	N	Y	Henke et al., (1993)			Projects and Concert	RACE		
	Extended Influence	N		Wheelwright and Clark (1992)						
	Accountability	N		Katzenbach and Smith (1993)						
	Empowerment	Y	Y	Wellins et al., (1991), Murphy and Levinson (1995)	X	X		RACE		
	Communication	Y	Y	Kahn and McDonough (1997)	X		HP, Jaguar-Ford (Intgr. Eng)	RACE		
	Initial Integration	N		De Meyer (1989), Tuckman (1965), Robbins and Finley (1995)						
	Co-location	N		Hirji (1999), Rafii (1995), Stalk and Hout (1990), Melymuka (1997), De Meyer (1989)						
	Complementary Skills	Y		Katzenbach and Smith (1993)	X			SEGAPAN		
	Training	N		Taguri (1995)			Dana, Xerox, Hitachi, Volkswagen and Bombardier	SEGAPAN, RACE		
	Rewards	Y	Y	Hauptman and Hirji (1999)	X	X	Project Level	RACE		
Project Management	Project Leader	Y	Y	Smith and Reinertsen (1991)	X	X	Project Level	RACE and 5X5 Frmwk		
	Measures of Performance	N	Y	Wheelwright and Clark (1992), Dimancescu and Dwenger (1996)	X	X		RACE, McGrath		
	Concurrency	Y		Prasad (1996 and 1997), Turino (1992)	X		Airbus	5X5 Frmwk		
	Project Planning	N	Y	Lock (1997), Smith and Reinertsen (1991), Wheelwright and Clark (1992)	X			RACE		
	Reporting Mechanisms	N		Dimancescu and Dwenger (1996)			Meritor	RACE		
	Resource Control	N	Y	Lock (1997), Badiru (1952)	X			5X5 Framework, RACE		
	Global Launch	N	Y	Subramaniam (1998)			HP, GKN, J&J			
	Project Trasfer	N	Y				Toshiba, NEC, Meritor			

Appendix 6. Sources for the CETGI Tool Elements

Explanatory Note: This appendix presents the sources of the elements (or GCE areas assessed) and sub-elements (second column) embedded in the CETGI knowledge base. The third column shows if the sub-elements were found correlated to NPD success on the author's or other studies. The fourth column shows if they were common in high performing teams. The fifth column shows their underpinning literature. The next three columns show specific studies where the sub-elements were covered. The next column presents current CE assessment tools, which are strong on the sub-elements. The final two columns show whether the sub-elements were included by expert advice or through the industrial application of the tool. Read Submission 6 for further detail on these sources.

Elements		Stat. Sign.	SOURCES: Ranked highly Imp	Literature	INTERPROD	1998 GNPD Survey	GNPD Case Studies	Other CE Assess. Tools	Expert Feedback	Tool Application
Change Management	Change Policy	Y		Lock (1997), Meredith (1995), Harrison (1992)	X			5X5 Framework	X (Mayf)	
	Measurement of Changes	N		Lock (1997), Wheelwright and Clark (1992)						
	Integration of Changes to Overall Project	N		Lock (1997), Wheelwright and Clark (1992)						
	Formal Change Mechanisms	N		Harrison (1992), Lock (1997)						
	Change Control Board	Y		Lock (1997)	X					
	Learning from Changes	N		Lock (1997), Wheelwright and Clark (1992)						
Product Development Process	Customer Focus	Y		Rothwell (1985) - SAPPHO, Cooper and Kleinschmidt (1979, 1987 and 1990) - NEWPROD	X			RACE		
	Commonality	N		Wheelwright and Clark (1992)			Dana, Ford, BMW-Rover, Volkswagen, HP, Ericsson, Toshiba, Raychem, Concert, Bombardier, Airbus	RACE		
	Formal Communication	N	Y	Cooper and Kleinschmidt (1993), InterMatrix (1997), Miles (1997)		X	Project Level			
	High Level Reviews	N		Graber (1996), Dimancescu and Dwenger (1996)		X	Hitachi, Toshiba, Airbus, Concert			
	Flexibility	N		Smith and Reinertsen (1991)						
	IT Interfacing	N								
	Learning	N		Wheelwright and Clark (1992), Smith and Reinertsen (1991)				RACE		
	Monitoring	N						RACE		
Product Engineering	Product Standards	N		Kotabe (1996), Fernandes (1995), McGrath et al., (1992)		X	Titan	McGrath, RACE		
	Product Modularity	Y		Kotabe (1996), Graber (1996), Sakakibara (1995), Cutherell (1996), Meyer et al., (1997)	X	X	Rover, Dana, Lucas Automotive	Menthor Graphics / RACE II		
	Derivatives	N		Smith and Reinertsen (1991)			Toshiba, NEC			
	Carry-Over Design	N		Smith and Reinertsen (1991), Wheelwright and Clark (1992)			Ford / VW			
	Learning	N								
Supply Chain Management	Core Suppliers	Y		Clark and Fujimoto (1991), Lutz (1996)	X		NEC, Rover			
	Integration	Y		Clark and Fujimoto (1991), Wheelwright and Clark (1992)	X		Ford	BEGAPAN		
	Global Supply	N					Ford, Airbus			
	Supplier Capability	N					Airbus, Rover			
	Learning	N		Smith and Reinertsen (1991)						

Appendix 6. Sources for the CETGI Tool Elements (2 of 3)

			SOURCES							
Elements		Stat. Sign.	Ranked highly imp	Literature	INTERPROD	1998 GNPD Survey	GNPD Case Studies	Other CE Assess. Tools	Expert Feedback	Tool Application
IT Infrastructure	IT Planning	N		Stark (1992)				RACE II		
	Integration	N		Hauptman and Hirji (1999), Kahn and McDonough (1997), Hameri and Nihtila (1997)			Airbus	RACE II		
	Communication	N	Y	Perrin (1996), Kleinrock (1961), Wood (1996), Roccapriore (1996)		X	Project Level	RACE II		
	Project Management	N		Cleland (1994)		X	Ricoh, Raychem, Hitachi, BMW-Rover, Ford, Toshiba, Rolls Royce Motor Cars, British Steel, J&J, Lucas	RACE II		
	Change Control Management	N		Cleland (1994)						
	Product Data Management	N	Y	Gould (1997), Senn (1990), Brown (1993), Medhat (1994), www.pdmic.com/undrstnd.html		X	Ford, B Ae, Airbus, AB Automotive Electronics, GKN and Dana	RACE / SEGAPAN		
	Design Software	N	Y	Deitz (1996)	X	X		SEGAPAN, RACE		
	Groupware	N		Bouteiller at al., (1996), Wilbur (1995), Line and Syvertsen (1996), Kirkpatrick (1993)				RACE		
Design Tools and Techniques	Customer Requirements' Capture	Y		Cook (1997), Chenan and Unny (1994), Prasad (1996)	X			SEGAPAN, RACE		
	Risk Assessment	N		Dale (1994)				RACE		
	Quality Assurance	N		Prasad (1996)						
	Creativity	N		Buzan (1997), Braham (1992)						
	Design for Manufacture	Y		Ashley (1995)	X			RACE, SEGAPAN		
	Rapid Prototyping	Y			X					
	Value Engineering	N						SEGAPAN, SXS Frmwk		NASTECH

Appendix 6. Sources for the CETGI Tool Elements (3 of 3)

Attribute	Level	Level Description	Examples and comments
Levels of Bill of Materials	Low	1 to 2 Levels	Nuts and Bolts (1) / Shoe (2)
	Medium	3 to 5 Levels	Lamp (3) / Bicycle (4) / Automotive Steering Column and Mobile Phone (5)
	High	More than 5 Levels	Automobile (6 to 7) / Aircraft (7 to 9)
Level of product elements' interaction	Low	Static and isolated subsystems	Wheel
	Medium	Dynamic and isolated subsystems	Office chair, door latch
		Static and linked subsystems with low interaction	
	High	Dynamic and linked subsystems with high interaction	Aircraft, automobile, steering column, mobile phone
Inter-Centres Transactions	Low	Providing critical design information	One team develops the core product and other team(s) contribute with idea generation and/or market information
	Medium	Customisation to local markets or manufacturing transfer	One team develops the core product and other team(s) customise this product to local markets or transfer this product to manufacturing
	High	System integration projects	Two or more teams working in parallel, contributing each with at least 25% of the total time of the project design work (total man-hours)
Level of decision making centralisation from parent company	Low	All decisions are made autonomously by centres	
	Medium	Projects are approved by corporate or parent company	
		Project budget and objectives selected autonomously by design centres	
	High	Projects and budget is approved by corporate or parent company	
		Project objectives are set either autonomously by design centre or together with corporate or parent company	
Product sensitivity to target markets	Low	Target market is only one country or even if it is various countries, its geographic conditions (Climate, culture, language, etc.) do not impact our product	Stationery such as staplers a personal watch
	Medium	The specific geographic conditions of the target market have a medium impact on the product	Lamps where voltage differs
	High	The specific geographic conditions of the target market have a high impact on the product	Mobile phone where the graphic user interfase and some telecom protocols must be customised to local markets Automobiles where different petrol is used, the side of the steering wheel and other regulations differ (e.g. Thatcham, crash, etc).
Supplier Dependency	High	Supplier engineered parts are more than 20% of our total engineered parts	
	Medium	Supplier engineered parts are between 10% and 20% of our total engineered parts	
	Low	Supplier engineered parts are less than 10% of our total engineered parts	

Appendix 7. The Case Profile and its Differentiating Attributes

Explanatory Note: An algorithm of the CETGI software uses the 'Case Profile' to suggest the list of customised and prioritised actions to the assessed companies. This profile contains various parameters (called by the author 'differentiating attributes') which describe the assessed case: the characteristics of the products (e.g. levels of bill of materials and components' interaction), the type of transactions between development centres, the autonomy from the parent company, the suppliers' contribution to the project and performance pressures in terms of costs, quality and time. Three levels were defined for each attribute (low, medium and high). The software uses numbers to recognise the attributes and their levels. Submission 6 describes the sources of each attribute.

Attribute	Level	Level Description	Examples and comments
Pressure to reduce development cycle-times	Low	Introducing a product late in the market represents a maximum of 5% loss of profit over the product life-cycle	Some furniture products, fine china, basic automotive components (e.g. air filters)
		Project development time is not critical for our survival	
	Medium	Introducing a product late in the market represents between 5% to 20% of loss of profit over the product life-cycle	Some automotive components (e.g. rear mirrors, seat belts) / Some electronics products (e.g. tape recorders, TV sets)
	High	Introducing a product late in the market represents a minimum of 20% loss of profit over the product life-cycle or even the lost of business	Some electronics products such as computers, data storage devices, etc. / New first tier supplied automotive components
		Our customer gives us a product delivery deadline that we must satisfy	
		Competitors often launch the products before we do	
Pressure to reduce product-unit recurring costs	Low	Our customers don't see product costs as a critical factor, compared to others such as product performance	Luxury products or those offering a special technological attribute as main selling point
		We have a niche market with certain control on our profit margins	
	Medium	Although we have to reduce periodically our costs, they are not decisive for our short term survival	Some OEM companies in growing markets
		We still set our prices	
	High	Our customers determine our sale price and they are highly sensitive to the product cost	Some tier supplied components / Some OEM companies in mature markets
		Our competitors are continually offering lower priced products in the same market segment	
		Our variable costs are too variable	
Pressure to reduce development project expenses	Low	Our project development expenses are not critical and we do not want to waste our time calculating how much we spent	
	Medium	We can have certain flexibility in terms of project development expense	
		We prefer to spend more when developing products in order to be first in the market	
	High	There is pressure from our customers to reduce project development expenses	
		Previous projects have spent more budget than originally planned	
Pressure to improve product quality	Low	Normal market requirements on product quality, reliability is not a critical issue	
		Our customers do not demand us to have quality systems in place	
	Medium	Product quality and reliability are important, but not critical to the life of product users	Electronic calculator, automobile radio
		Cost of defects is significant	
	High	Strong market requirements in terms of product quality, product reliability is critical to the life of product users	Aircraft engine or automobile brake
		Our competitors are implementing strong quality initiatives	

Appendix 7. The Case Profile and its Differentiating Attributes (2 of 2)

			CE Assessment Tool																			
	CETGI Requirements	Priority	Mentor Graphics		RACE		Mc Grath Maturity Model		SEGAPAN		RACE II		BRACE		PACE		5X5 Framework		Cranfield Tool		CETGI Tool	CETGI Tool Scores
Output	Company specific improvements	9	3	27	3	27	0	0	3	27	3	27	3	27	3	27	3	27	3	27	5	45
	Action prioritisation support	9	3	27	3	27	0	0	3	27	3	27	3	27	0	0	3	27	1	9	5	45
	Including a performance perspective	9	3	27	5	45	3	27	1	9	5	45	5	45	3	27	5	45	0	0	5	45
	Output visibility	5	5	25	3	15	0	0	3	15	3	15	3	15	1	5	0	0	0	0	5	25
	Scenario evaluation	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	15
	Automatic feedback to participant	1	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	5	5
Method	Multifunctional participation	9	3	27	5	45	3	27	3	27	5	45	5	45	3	27	3	27	3	27	5	45
	Decision makers involvement	9	3	27	5	45	1	9	1	9	3	27	3	27	3	27	5	45	5	45	5	45
	Replication (Std. / low ambiguity)	9	3	27	3	27	1	9	3	27	5	45	5	45	3	27	3	27	3	27	5	45
	Upgradabiity	9	3	27	3	27	3	27	5	45	3	27	3	27	1	9	1	9	1	9	5	45
	User friendliness	5	3	15	1	5	1	5	3	15	1	5	1	5	1	5	1	5	1	5	3	15
	Easy access	5	3	15	3	15	3	15	3	15	3	15	3	15	3	15	3	15	3	15	3	15
	Benchmarking capability	5	1	5	1	5	1	5	3	15	1	5	1	5	1	5	0	0	0	0	3	15
	Implementation guidelines	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	25	5	25	3	15
	Virtual assessment capability	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	25
	Low time and org. resources involved	1	5	5	1	1	5	5	3	3	1	1	1	1	3	3	1	1	1	1	1	1
	Self-assessment capability	1	5	5	0	0	5	5	3	3	0	0	0	0	5	5	5	5	5	5	1	1
	Multilingual capabilit	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elements	Relevance to Global CE	9	1	9	1	9	1	9	1	9	3	27	1	9	1	9	1	9	1	9	5	45
	Clarity of dimensions and scales	9	3	27	5	45	1	9	1	9	5	45	5	45	1	9	3	27	1	9	5	45
	Inclusion of basic CE practices	9	3	27	3	27	3	27	3	27	3	27	3	27	3	27	3	27	3	27	3	27
	Industrial examples provided	5	0	0	0	0	0	0	0	0	0	0	0	0	1	5	0	0	1	5	0	0
	Industrial backing	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	15	5	25
	Balanced model	1	3	3	3	3	3	3	1	1	3	3	3	3	0	0	1	1	0	0	3	3
	Low number of elements	1	3	3	0	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Statistical backinc	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	3
		Total Impact:		328		368		187		286		386		368		232		322		261		595

Priorities: 9 = Must, 5= Want, 1=Bonus
The column below the name of the tool shows its level of satisfaction of the requirement: 5=High, 3=Medium, 1=Low, 0=No impact
The next column shows the weighted impact (Priority X Level of Satisfaction)